Managing Solar PV Adoption in Rural Sub-Saharan Africa: Insights from Zambia’s Energy Transition

(A Thesis as a Collection of Papers)

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Declaration

I, Hillary Chanda, confirm that this thesis is my own work and has been composed by myself. It has not been submitted, in whole or in part, for any other degree or qualification at this or any other institution.

This thesis is submitted by publication. The majority of the work presented was undertaken by me, with appropriate attribution given to all co-authors and collaborators. I have clearly indicated the contributions of each author to the seven (7) peer reviewed published works included within this thesis, which collectively underwent expert review by twenty-five (25) reviewers.

All sources of information used have been appropriately acknowledged through citation.

Date: 26th November 2025

Hillary Chanda.

Dedication

To my mother, Mercy Zyambo Chanda, whose unwavering strength, sacrifice, and faith in education have shaped the path I walk today.

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This thesis has been a deeply personal and professional journey, and it would not have been possible without the support, mentorship, and contributions of many individuals and institutions starting with my children Caleb, Joshua, Shadrach and Jane, and their mother, all to whom I will forever be grateful. I am also grateful to my brothers and sisters for their support.

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Above all, credit and glory go to God in the highest and Jesus Christ my Lord.

Abstract

This thesis investigates the governance, adoption, and livelihood implications of solar photovoltaic technology in rural Zambia. Although decentralised solar PV deployment has expanded rapidly, there remains a clearly defined research and policy gap in understanding how rural communities adopt, use, manage, and sustain these systems over time. Existing policy frameworks largely prioritise technical rollout while overlooking weak community engagement, informal governance arrangements, and the paradoxical use of ecologically damaging income sources, such as charcoal production, to finance solar technologies. This gap constrains effective and equitable energy transitions in rural contexts and limits the long-term sustainability of decentralised solar investments. Against this background, the principal aim of this study is to examine how solar PV adoption and management are shaped by community needs, environmental trade-offs, and the role of informal and non-state actors within the broader energy transition. This aim is important because without such understanding, decentralised energy policies risk reinforcing environmental degradation, social inequality, and system abandonment rather than delivering durable development benefits. The research was conducted over 30 months from October 2022 to May 2025 in Central Province (Kapiri and Mkushi Rural), Lusaka Province (Chongwe Rural) and Copperbelt Province (Chingola Rural, Luano). These sites were selected due to their high levels of off-grid solar penetration, active informal charcoal economies, limited formal waste management infrastructure for end-of-life solar products, and marked socio-ecological diversity. The study applies the Rural Development Stakeholder Hybrid Adoption Model, a theoretical framework developed in this thesis. This framework systematically examines behavioural, social, institutional, and environmental dimensions influencing rural energy transitions. Using 108 in depth interviews, 12 focus group discussions, and extensive participant observation, the study identifies several novel findings. First, the Clean Energy - Deforestation Paradox, whereby charcoal production and non-timber forest product harvesting are used to finance the acquisition of solar PV systems. Second, the critical role of peer learning and local ownership in sustaining solar use, defined in this study as the continued functional operation, maintenance, and long-term reliance on solar technologies for everyday energy needs. Third, the emergence of unregulated solar e-waste in off-grid regions, understood as the informal disposal, burial, burning, or unsafe storage of damaged or obsolete solar components outside formal waste management systems. Fourth, the previously underexplored influence of White commercial farmers in community solar PV adoption, electrification and infrastructure investment.

The thesis concludes with policy recommendations that emphasise community participation, gender equity, integrated energy and environmental governance, financial innovation, and inclusive regulation, advancing a vision for just, locally grounded, and ecologically resilient solar energy transitions in Sub-Saharan Africa.

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List of Abbreviations

- AfDB – African Development Bank
- AWEEF – African Women in Energy and Environment Foundation
- CUTS Zambia – Consumer Unity & Trust Society Zambia
- ERB – Energy Regulation Board
- ESCO – Energy Service Company
- FGDs – Focus Group Discussions
- GIZ – Deutsche Gesellschaft für Internationale Zusammenarbeit
- IDIs – In-Depth Interviews
- IRENA – International Renewable Energy Agency
- IUCN – International Union for Conservation of Nature
- MoA – Ministry of Agriculture
- MoE – Ministry of Energy
- MoF – Ministry of Finance
- MoGE – Ministry of General Education
- MoGEE – Ministry of Green Economy and Environment
- MoH – Ministry of Health
- MoST – Ministry of Science and Technology
- MLGRD – Ministry of Local Government and Rural Development
- MSMED – Ministry of Small and Medium Enterprises Development
- NTFP – Non-Timber Forest Product
- NTFPs – Non-Timber Forest Products
- NST – North Swaka Trust
- PAYG – Pay-As-You-Go
- PV – Photovoltaic
- REA – Rural Electrification Authority
- RUDSHAM – Rural Development Stakeholder Hybrid Adoption Model
- SLT – Social Learning Theory
- SNV – SNV Netherlands Development Organisation
- TPB – Theory of Planned Behaviour
- TAM – Technology Acceptance Model
- UNDP – United Nations Development Programme
- UNCDF – United Nations Capital Development Fund
- UN Women Zambia – United Nations Women Zambia
- WCFs – White Commercial Farmers
- WDCs – Ward Development Committees
- WFP – World Food Programme
- WWF Zambia – Worldwide Fund for Nature Zambia
- ZABS – Zambia Bureau of Standards
- ZACA – Zambia Consumer Association

- ZAFFICO – Zambia Forestry and Forest Industries Corporation
- ZAMSIF – Zambia Social Investment Fund
- ZARI – Zambia Agricultural Research Institute
- ZAWA – Zambia Wildlife Authority
- ZAMSTATS – Zambia Statistics Agency
- ZCSA – Zambia Compulsory Standards Agency
- ZEMA – Zambia Environmental Management Agency
- ZIPAR – Zambia Institute for Policy Analysis and Research
- ZRA – Zambia Revenue Authority
- ZESCO – Zambia Electricity Supply Corporation
- ZANIS – Zambia News and Information Services
- ZCI – Zambia Chamber of Commerce and Industry
- ZAPH – Zambia Association for Public Health

Chapter 1: Introduction

1.1 Introduction

This study critically examines the adoption, management, and provision of solar photovoltaic (PV) systems in rural Zambia, focusing on the socio-economic, environmental, and behavioural dimensions of this transition. While national energy strategies often prioritise top-down, supply side interventions, this research places emphasis on the perspectives and lived experiences of rural communities, particularly those unconnected to the national electricity grid. It investigates the persistent mismatch between solar PV provision and local energy needs and how community level dynamics shape the uptake, use, and long-term management of solar technologies.

Understanding Zambia's rural energy landscape necessitates a nuanced analysis of the complex interplay between traditional energy practices, socio-cultural behaviours, and infrastructural limitations. Most of the world's energy poor populations reside in Sub-Saharan Africa (SSA), where over 600 million people remain without access to electricity (Chanda et al., 2025a; IEA, 2024; M. M. Santos et al., 2023). In SSA, more than 80% of rural dwellers lack access to modern energy sources (Mugisha et al., 2021). Despite Africa's vast solar potential, receiving insolation levels between 4 and 7 kWh/m²/day, renewable energy technologies remain marginal in national energy portfolios (Dagnachew et al., 2020; IEA, 2021).

This study critically examines the adoption, management, and provision of solar photovoltaic (PV) systems in rural Zambia, focusing on the socio-economic, environmental, and behavioural dimensions of this transition. While national energy strategies often prioritise top-down, supply-side interventions, the research carried out for this thesis places emphasis on the perspectives and lived experiences of rural communities - particularly those unconnected to the national electricity grid.

1.1.1 Zambia's Energy Paradox

Zambia epitomises the energy paradox facing many SSA countries. Although the country enjoys abundant solar resources (averaging 5.5 kWh/m²/day and over 3,000 sunshine hours annually), solar accounts for just 3% of its total installed electricity capacity (ERB Report, 2023). As of 2024, Zambia's total installed generation capacity stood at 3,870 MW, yet a deficit of approximately 950 MW persists, despite electricity imports and incremental solar integration (ERB, 2024; ZESCO, 2024a). National access to electricity remains critically low, with 64% to 84% of the population unconnected; most acutely felt in rural areas, where electrification rates remain below 15% (Chambalile et al., 2024; Kapole et al., 2023; MOE, 2024).

The energy crisis is compounded by the country's overreliance on hydroelectric power, which contributes over 85% of electricity supply (MOE, 2024). Climate-induced droughts have reduced water levels, resulting in chronic power shortages and load shedding lasting up to 21 hours per day (ZESCO, 2024a). The economic implications are profound, affecting manufacturing output, employment, tax revenues, and poverty alleviation efforts (CSO, 2018). In response, the Zambian government has prioritised renewable energy in its 8th National Development Plan and introduced initiatives like the Renewable Energy Feed-in Tariff (REFiT) to encourage private sector investment (MOE, 2019).

1.1.2 The Promise and Limitations of Solar PV

Solar PV has emerged as a critical pathway for expanding decentralised energy access globally, particularly in remote, off-grid regions (Budzianowski et al., 2018; IEA, 2024). The introduction of pay-as-you-go (PAYG) models, mobile metering, and mini-grid technologies has improved affordability and accessibility (GOGLA, 2023; Nygaard et al., 2016). By 2023, more than 40 million people in SSA accessed electricity via solar home systems (SHS), a nearly fourfold increase over the previous five years (World Energy Outlook, 2024). An additional 30 million used SHS as a supplementary source in areas with unreliable grid supply. Financing models such as Energy-as-a-Service have shown promise in making SHS affordable even for the poorest households (GET.Invest, 2024).

Nevertheless, significant challenges persist. High upfront investment costs, limited technical expertise, unreliable supply chains, and poor after-sales service have constrained the full potential of solar PV (Khan et al., 2021; M. M. Santos et al., 2023). Public financing remains insufficient, while donor dependency and fragmented interventions limit scalability and long-term sustainability (Sovacool and Drupady, 2016). Furthermore, the proliferation of counterfeit products and unregulated e-waste disposal poses emergent risks to health and the environment (Bauwens et al., 2022; Brunet et al., 2018).

1.1.3 Biomass Dependence and Environmental Trade-Offs

In rural Zambia, traditional biomass fuels, particularly charcoal and firewood, remain the dominant sources of energy. An estimated 98% of rural households depend on biomass for cooking and heating (Kaoma and Gheewala, 2020). Charcoal production is not only a livelihood strategy but also a major contributor to deforestation, land degradation, and carbon emissions. The continued use of biomass thus presents a dilemma: while it is economically vital for rural populations, its environmental costs are unsustainable (Kaoma and Gheewala, 2021).

Solar PV offers a potential avenue for reducing reliance on biomass and its associated ecological harms. However, the transition from charcoal to cleaner technologies is fraught with economic and behavioural barriers. Households may resist adopting new technologies due to cultural preferences, lack of awareness, or perceived unreliability (Adams and Asante, 2020; Antwi and Ley, 2021). A successful energy transition must therefore address these social and economic trade-offs while aligning with local development priorities.

1.1.4 Community Dynamics and Informal Energy Actors

Emerging research underscores the importance of local agency in shaping energy transitions. Community-led adoption pathways, such as social learning, peer influence, and informal leadership, often determine the success or failure of solar projects (Herraiz-Cañete et al., 2022; Hoffman and High-Pippert, 2005; Hoicka et al., 2021; Mugisha et al., 2021). It is important to examine whether these PV systems align with household livelihood strategies, including wild food harvesting, microenterprise, and irrigation activities central to income diversification and climate resilience (Blimpo et al., 2020; Vanadzina et al., 2019). Recognising these grassroots dynamics is essential for designing inclusive energy policies that resonate with local needs.

1.1.5 Financing

While solar technology costs have declined globally, the capital intensity of solar PV remains a formidable barrier in rural Zambia (IEA, 2024). Government budgets and donor funding have proven insufficient to ensure sustained expansion, necessitating innovative financing mechanisms and community-based models (Khan et al., 2021; Sovacool, 2013). At the same time, growing solar deployment introduces new challenges, particularly around end-of-life system management.

1.1.6 End-of-Life Management

Growth in solar PV deployment introduces new challenges, particularly around end-of-life system management. Issues such as battery degradation, inadequate disposal practices, and the proliferation of substandard technologies necessitate urgent regulatory and educational interventions (Bauwens et al., 2022; Brunet et al., 2018). Without addressing these lifecycle challenges, solar PV risks becoming an unsustainable solution, introducing new environmental burdens to rural areas rather than alleviating them.

1.1.7 Research Justification

Despite increased scholarly and policy attention to decentralised renewable energy, there remains a paucity of empirical studies focused on the specific realities of rural solar PV users in Zambia. Most interventions are designed with minimal input from rural communities, leading to poor uptake, low system sustainability, and unmet expectations (Ambole et al., 2021; Antwi and Ley, 2021). This study seeks to fill this gap by grounding analysis in the socio-cultural, economic, and environmental contexts that shape energy behaviour in rural Zambia.

The research aligns with Zambia's policy goals under its national development framework and contributes to broader global objectives such as Sustainable Development Goal 7 (SDG 7), which calls for universal access to affordable, reliable, sustainable, and modern energy. By placing rural voices and informal actors at the centre of the analysis, this study offers a more holistic understanding of how solar PV adoption and management unfold on the ground and what can be done to enhance their effectiveness and sustainability.

1.2 Research Aim

The central aim of this PhD is to examine how solar PV adoption and management in rural Zambia is shaped by community needs, environmental trade-offs, and informal actors within the broader energy transition. This examination focuses on five research questions to be addressed in the chapters below:

- How does the expansion of solar photovoltaic technology in rural Zambia interact with existing patterns of biomass energy use, particularly charcoal dependence, and what are the resulting implications for deforestation, environmental sustainability, and national energy transition policy?
- In what ways do community driven adoption pathways, including social learning, peer influence, and local ownership structures, shape the uptake, maintenance, and long-term sustainability of solar photovoltaic systems in rural Zambia, and how do these processes align with or diverge from externally designed interventions?
- What challenges are associated with the lifecycle management of solar photovoltaic systems in rural Zambia, particularly in relation to informal waste disposal practices, low levels of technical and consumer literacy, and the circulation of counterfeit or substandard technologies?
- How do nontraditional energy actors, including White commercial farmers and self-financing rural households, influence the accessibility, distribution, and developmental outcomes of decentralised solar photovoltaic systems in off-grid rural regions?
- To what extent does solar photovoltaic adoption support or undermine rural livelihood strategies in Zambia, particularly through its interaction with non-timber forest products (NTFP) such as honey, mushrooms, and traditional beer production, as well as seasonal income generating activities?

1.3 Research Objectives

- To examine the environmental and energy transition dynamics linked to solar PV expansion in rural Zambia, particularly in relation to the country's reliance on biomass fuels like charcoal, and its implications for deforestation, energy policy, and sustainability.
- To explore the role of community driven adoption pathways, including social learning, peer influence, and local ownership structures, in supporting or limiting the uptake, use, and maintenance of solar PV systems, and how these align or conflict with external supply side interventions.
- To assess the emerging challenges related to solar PV waste and system reliability in rural Zambia, focusing on the effects of low consumer literacy,

unregulated disposal practices, and the influx of counterfeit or substandard solar technologies.

- To investigate the roles played by non-traditional energy actors, including White commercial farmers and self-financing rural households, in facilitating or obstructing solar PV access, community development, and infrastructure improvement in off-grid regions.
- To analyse the extent to which solar PV adoption supports or undermines rural livelihoods, with a particular focus on its integration with non-timber forest products (e.g., honey, mushrooms, traditional beer) and seasonal income-generating activities in Zambia's rural communities.

1.4 Thesis Structure Overview

The chapters that follow build on this introductory foundation. Chapter 2 presents a critical review of the literature, highlighting key debates on rural energy access, solar PV adoption, and sustainability challenges in Zambia and Sub-Saharan Africa. Chapter 3 introduces the theoretical framework underpinning the study, RUDSHAM, and its integration with established behavioural theories. Chapter 4 details the research methodology, study sites, and data collection approaches. Chapters 5 to 11 comprise seven empirical articles, each addressing a specific research objective and theme, from deforestation to solar adoption, e-waste, livelihoods, and community dynamics. Chapter 12 synthesises policy recommendations based on the findings, while Chapter 13 offers concluding reflections and directions for future research.

Chapter 2: Literature Review

This chapter critically examines existing scholarly work on rural electrification, solar photovoltaic adoption, energy poverty, environmental sustainability, and community centred energy transitions, with a particular focus on Sub-Saharan Africa and comparable developing regions. The purpose of this review is to situate the present study within the broader academic and policy debates, to identify established knowledge, and to highlight key empirical and conceptual gaps that justify the current research. The chapter is structured thematically to reflect the dominant strands of literature relevant to this thesis. It begins by examining energy poverty and structural barriers to rural electrification. It then explores financing and capital constraints in Solar PV deployment, followed by assessments of technological potential and regional disparities in access. Subsequent sections critically review debates around household energy priorities, community participation, subsidy models, and the economic impacts of rural solar interventions. Later sections address demand forecasting, affordability challenges, and the role of productive uses of energy in livelihood improvement. The chapter concludes by synthesising key insights and demonstrating how the reviewed literature informs the study's research aims, objectives, and questions. This structure is designed to move from broad global and regional debates to more localised and practice based challenges, thereby creating a coherent analytical foundation for the empirical chapters that follow.

2.1 Energy Poverty

Mohammed Wazed et al. (2018) present a comprehensive review of sustainable solar irrigation systems in Sub-Saharan Africa, demonstrating how solar technologies can support agricultural productivity while addressing chronic energy access deficits. Off-grid solar technology is increasingly recognised as a transformative solution for addressing energy poverty across Sub-Saharan Africa (SSA), where electricity infrastructure remains severely underdeveloped (Mohammed Wazed et al., 2018). Globally, an estimated 750 million people still lack access to electricity, with 80% of these residing in SSA (World Energy Outlook, 2024). The continent faces a dual crisis: 600 million people remain without electricity, and approximately one billion lack access to clean cooking facilities (IEA, 2025). Although recent IEA data suggest a slight improvement, electricity access increased by over 10 million people between 2022 and 2023, this progress follows a period of stagnation where population growth outpaced new connections (IEA, 2024).

The energy access deficit remains most acute in SSA, which accounts for the vast majority of the global unelectrified population. In 2018, the region had a population of 915 million, of whom 68% lacked electricity access (Okoye and Oranekwu-Okoye, 2018). This crisis is exacerbated by persistent demand-side constraints (Blimpo et al., 2020; IEA, 2025). Rural communities, which constitute 60% of Africa's unelectrified population, often exist beyond the reach of national grids (Mugisha et al., 2021; World Energy Outlook, 2024). The prevailing income levels, frequently below USD 1.50 per day, pose significant challenges to cost reflective electricity tariffs (Mugisha et al., 2021). Consequently, weak rural purchasing power continues to hinder Solar PV deployment (Chanda et al., 2025a; Vanadzina et al., 2019).

2.2 Solar PV Funding and Capital Challenges

The deployment of Solar PV systems in SSA is fundamentally constrained by financial limitations. Ameli et al. (2020) investigated patterns of climate related investment in developing economies and showed that higher financing costs create a persistent investment trap that constrains low carbon technology deployment. Developing nations struggle to attract sufficient capital, with financing costs in SSA up to seven times higher than those in developed economies (Ameli et al., 2020; IEA, 2021; World Energy Outlook, 2020). These capital challenges are compounded by the economic disruptions caused by COVID-19, which interrupted a previously consistent trajectory toward universal energy access (World Energy Outlook, 2020).

The pandemic disproportionately affected SSA, stalling electrification efforts and widening existing inequalities (IEA, 2021; REN21, 2020). In response, many renewable energy initiatives, particularly in rural regions, now rely heavily on concessional and blended finance mechanisms to remain viable (IEA, 2024, 2021). These financial arrangements are essential for overcoming structural barriers to Solar PV implementation in under-resourced communities.

2.3 Solar PV Potential

Despite these constraints, international experiences suggest that Solar PV holds considerable potential for SSA. Mugisha et al. (2021) assess the opportunities and challenges associated with off-grid solar systems in Kenya, Ethiopia, and Rwanda, highlighting both the development benefits and structural constraints that shape Solar PV uptake in Eastern Africa. In Bangladesh, the successful deployment of nearly three million off-grid systems was underpinned by a strong microfinance network and a focus on service quality and consumer trust (Mugisha et al., 2021). In SSA, Solar PV technologies are increasingly used to power water supply systems and support agricultural irrigation, thereby improving rural livelihoods (Mugisha et al., 2021; Xie et al., 2021). Studies reveal that Solar PV has a wide array of applications, including productive use in farming (Chanda et al., 2025a, 2025b, 2025c; Xie et al., 2021). The technology is now more affordable, with reduced carbon emissions and improved energy efficiency, making it an ideal option for rural electrification (Durga et al., 2024; Schmitter et al., 2018). Solar powered water pumps, for instance, require less labour and are more cost-effective than diesel or electric pumps (Chandel et al., 2015; Mohammed Wazed et al., 2018; Schmitter et al., 2018).

The rapid growth in Solar PV adoption is notable. Between 2008 and 2016, installations increased by over 40 fold globally (Moner-Girona et al., 2018), and this trend is continuing (IEA, 2025, 2024). Nevertheless, infrastructural deficiencies and inadequate capital investment in rural SSA remain significant bottlenecks (Amjath-

Babu et al., 2016; Durga et al., 2024). As a result, Solar PV remains largely inaccessible for many SSA households (Baurzhan & Jenkins, 2016), especially in sparsely populated regions where low demand per capita further disincentivises investment (Hailu and Kumsa, 2020; Mugisha et al., 2021).

2.4 Energy Poverty in Africa

The World Energy Outlook (2020) provides a global analysis of energy demand, supply, and technology pathways, and identifies Sub-Saharan Africa as a region with exceptional solar resources but persistent deficits in modern energy access. Sub-Saharan Africa is endowed with exceptional solar potential, receiving insolation levels between 4 and 7 kWh/m²/day, among the highest globally (Moner-Girona et al., 2018; Winklmaier and Bazan Santos, 2018; World Energy Outlook, 2020). Coupled with falling Solar PV costs and increased energy conversion efficiency, this makes solar power a promising alternative to grid extension (Winklmaier and Bazan Santos, 2018).

Despite this immense potential, over 80% of SSA's rural population, who constitute 60% of the total population, remain without electricity (Moner-Girona et al., 2018; Mugisha et al., 2021). The region continues to experience the world's most severe energy poverty (IEA, 2025). Advances in PV technology have significantly lowered system costs, particularly for solar panels and batteries (Egli et al., 2023; Moner-Girona et al., 2018), and global PV capacity expanded nearly twentyfold between 2010 and 2020 (World Energy Outlook, 2020). Yet, in SSA, Solar PV has yet to achieve transformative impact due to systemic market failures and limited economic viability as a stand-alone energy solution (Okoye and Oranekwu-Okoye, 2018; Vanadzina et al., 2019; Xie et al., 2021). Scholars argue that for Solar PV to be a viable alternative, financial and institutional support must be accompanied by community awareness, participation, and access to credit for technology acquisition (Schmitter et al., 2018). Without these enablers, Solar PV is unlikely to deliver sustainable energy access across the region.

2.5 Lighting Not Priority in Rural Areas

Bai et al. (2021) evaluate the effectiveness of a photovoltaic poverty alleviation project in China from a capital perspective, examining how Solar PV interventions influence income and welfare outcomes for low income households. While numerous scholars emphasise lighting as a critical energy need for rural communities due to its social and economic benefits, (Bai et al., 2021; Barman et al., 2017; Hicks and Ison, 2018; Rabetanetiarimanana et al., 2018), an increasing body of literature challenges this assumption. This body of work has strongly influenced policy narratives that equate the provision of basic lighting with meaningful progress in rural electrification. However, this emphasis can risk oversimplifying complex livelihood priorities by taking lighting as a universal proxy for development, rather than examining the specific aspirations and constraints of rural households. A growing set of empirical studies challenges the assumption that lighting is the primary or most urgent energy service for rural populations. These studies reveal that many households attach greater importance to electricity for productive uses, including welding, salons, carpentry, irrigation, and other income generating activities that directly support livelihoods (Batidzirai et al., 2021a; Chanda et al., 2025a; Chaurey et al., 2012; Winklmaier and Bazan Santos, 2018). From this perspective, programmes that focus narrowly on basic lighting risk under serving community needs and may fail to stimulate the broader economic benefits often promised by rural electrification initiatives.

Further, there is evidence that limited solar photovoltaic adoption can be partly explained by the relatively low priority attached to lighting when compared with more immediate concerns such as food security, education, and health related expenses. Baurzhan and Jenkins (2016) show that rural households frequently regard investment in solar systems as secondary, to be considered only after more pressing needs have been addressed. This suggests a misalignment between policy driven objectives and local energy preferences. Taken together, these studies indicate that effective solar interventions must engage with the full spectrum of rural energy aspirations rather than assuming lighting to be the dominant priority.

2.6 Addressing Gaps in Implementation and Research

Therefore, Solar PV system implementation in rural Africa necessitates critical re-evaluation and redesign. It is essential that systems be developed with active participation and consultation of rural end users (Chaurey et al., 2012; Davidson and Mwakasonda, 2004; REN21, 2020). Most rural households rely on traditional fuels, charcoal for heating, firewood for cooking, and paraffin for lighting, while living without high consumption appliances such as televisions or refrigerators (Mugisha et al., 2021). In such contexts, many rural dwellers only require power for basic uses like charging phones and radios, which limits the market for off-grid solar (Mugisha et al., 2021).

Furthermore, given widespread poverty, many rural residents prioritise economic needs over energy investment. The capital outlay required for a Solar PV system may be perceived as better spent on other necessities that contribute more directly to household income or welfare (Mugisha et al., 2021). Despite PV being the most researched renewable energy technology for rural electrification (Ikejemba et al., 2017), the deployment of off-grid systems continues to encounter sustainability and operational challenges (Pillot et al., 2019). Effective deployment of Solar PV systems requires integration into local socio-economic systems and a nuanced understanding of local behaviours and energy cultures. However, transdisciplinary research addressing these contextual dimensions is currently lacking (Belligoni et al., 2025; Ikejemba et al., 2017; Lawrence et al., 2022).

Moreover, the absence of region-specific evaluations of Solar PV projects in Africa presents a major research gap. Much of the literature and implementation guidance comes from Western contexts, with limited attention to sustainability or adoption challenges in Sub-Saharan Africa (World Energy Outlook, 2020). As Ikejemba and Schuur, (2020) argue, successful Solar PV implementation in SSA requires a deep understanding of remote and underserved communities and how systems can be tailored to function effectively in these unique environments.

2.7 Demand Forecasting and Affordability Challenges

Lombardi et al. (2019) developed an open-source stochastic model for generating high resolution multi energy load profiles in remote areas, illustrating how improved demand estimation can enhance the design of off-grid energy systems. Assessing energy demand in rural areas remains an unresolved challenge. A key issue is the absence of a universally accepted or standardised methodology for evaluating energy demand in off-grid regions (Lombardi et al., 2019). Consequently, mini-grid and Solar PV system designs are often based on estimations rather than actual consumption data, potentially resulting in oversized or underperforming systems (Herraiz-Cañete et al., 2022).

Forecasting rural energy needs is particularly complex in areas where there is no historical data because they have never been electrified (Mandelli et al., 2016). This often results in over or under estimations, especially where projections are made by stakeholders with vested interests (Williams et al., 2015). Additionally, the diversity of rural communities and the varying socio-economic conditions challenge the efficacy of “one size fits all” energy solutions. Customised approaches tailored to the specific needs and characteristics of each community are vital (Okoye and Oranekwu-Okoye, 2018).

Moreover, the affordability barrier in rural SSA hampers demand for renewable energy technologies (RETs). The combination of low household incomes and limited access to credit or institutional finance means that many end users cannot afford solar products, even when they are technically suitable (Gabriel et al., 2016). This points to a dual gap, one in demand estimation and another in demand affordability.

2.8 Advancing Community Participation and Ownership

Addressing these challenges requires greater emphasis on participatory energy planning. Adelhardt and Berneiser (2024) conducted a risk analysis of agrivoltaic projects in rural farming communities in Sub-Saharan Africa, emphasising the importance of local stakeholder engagement and ownership for project resilience. A growing body of literature stresses the need for stakeholder engagement, community capacity building, and long-term participation in renewable energy initiatives (Adelhardt and Berneiser, 2024). For example, Antwi and Ley (2021) identify inadequate community engagement as one of the primary bottlenecks in renewable energy project development in SSA.

Community energy, as defined in this context, refers to energy projects characterised by inclusive, participatory processes in planning, development, financing, ownership, and management, with benefits distributed locally (Hoicka et al., 2021; Walker and Devine-Wright, 2008). However, in practice, community involvement is often symbolic, undertaken merely to satisfy donor or regulatory expectations rather than to embed communities in decision making (Ambole et al., 2021).

Empirical findings show that meaningful community participation from the earliest planning stages is frequently overlooked (Chanda et al., 2025a; Vanegas Cantarero, 2020). Studies consistently report that renewable energy projects in developing countries suffer from a lack of local ownership and limited operational involvement by rural populations (Kapole et al., 2023). Community ownership and sense of agency can be significantly enhanced by employing bottom-up models, where local populations are empowered as the main agents throughout all phases, from inception through monitoring and evaluation (Adelhardt and Berneiser, 2024). Despite growing awareness of the importance of community involvement, many governments continue to engage rural citizens only nominally. Participation often takes the form of superficial consultation rather than genuine collaboration, primarily to appease external donors (Ambole et al., 2021). Yet, there is broad consensus in the literature that citizens should not merely be beneficiaries but active stakeholders in the planning and execution of renewable energy projects (Azimoh et al., 2017; Vanegas Cantarero, 2020).

2.9 Economic Feasibility of Rural Solar PV

Some scholars argue that Solar PV implementation in most African rural areas is not feasible due to the economic status of the targeted recipients and the lack of adequate community participation in project design, implementation, and maintenance (Baurzhan and Jenkins, 2016). Baurzhan and Jenkins (2016) analysed the affordability and appropriateness of off-grid Solar PV for rural electrification in Sub-Saharan African countries and concluded that off-grid Solar PV systems are not feasible financially or economically for rural households in SSA unless these technologies are subsidised externally. They proposed that rural electrification should rather focus on expanding national grids systematically, as opposed to deploying household-level Solar PV systems.

Nevertheless, there are examples illustrating that Solar PV can become commercially viable if implemented appropriately. A notable case is in Nepal, where 50% of the project costs are contributed by the local community (Hoffman and High-Pippert, 2005). This indicates the potential of community co-financing to enhance sustainability. Consequently, energy development strategies in SSA should be reoriented to work through Community Based Organisations (CBOs), with a renewed focus on tailored financing for small-scale, locally managed renewable energy projects (Butu et al., 2021; Lillo et al., 2015).

2.10 Subsidy Models and Access to Solar PV

However, Renewable Energy Communities in Africa face numerous challenges, including inadequate policy frameworks, unsustainable financial models, and limited community ownership (Mathew et al., 2023). Mathew et al. (2023) examined

Renewable Energy Communities in five African countries and identified key institutional and financial barriers that limit their contribution to inclusive energy access. Governments have introduced subsidies to promote renewable energy investment, for example, Zambia's Renewable Energy Feed-in Tariff (REMIT) aims to stimulate the sector (Chirambo, 2018). Yet, poorly structured subsidies often erode community ownership, particularly in instances where beneficiaries do not contribute financially. Evidence from India suggests that private entrepreneurship models outperformed subsidy based delivery systems in terms of sustainability and impact (Borah et al., 2014; Gómez-Hernández et al., 2019).

Supply side subsidies (SSS) have been instrumental in expanding off-grid solar markets in SSA by reducing operational risks for private companies and catalysing business growth. However, they do not adequately bridge the affordability gap for the poorest segments (DFID-UKaid, 2020). Demand side subsidies (DSS), which reduce the actual cost of solar products for end users, are emerging as a crucial complement. Post COVID-19 projections highlight that millions may remain unelectrified by 2030, especially in SSA, unless DSS is incorporated into subsidy frameworks (DFID-UKaid, 2020). DSS models are therefore vital to achieving SDG 7 in underserved rural contexts.

2.11 Evaluating Solar in Poverty Contexts

Despite being widely promoted as a poverty alleviation mechanism, Solar PV's actual contribution to economic development in SSA remains debated. Baurzhan and Jenkins (2016) and Martinot et al. (2002), examined the affordability, financing structures, and institutional design of solar programmes in Africa and Asia, and argued that there is limited empirical evidence linking SHS (Solar Home Systems) adoption with sustained rural poverty reduction. Feron (2016) also critiques the economic significance of SHS in transforming household income levels. Conversely, other studies reveal that SHS has enabled small scale entrepreneurial activities such as phone charging businesses and communal TV viewing centres (Barman et al., 2017).

Additionally, SHS has improved quality of life indicators, including indoor air quality, extended study time at night for school children, and reduced time spent collecting firewood, primarily a task falling on women and children (Bai et al., 2021; Rabetanetiarimanana et al., 2018). For example, the Energy Service Company (ESCO) project in Zambia demonstrated that Solar PV can support enhanced learning environments through improved night time lighting access (Baurzhan and Jenkins, 2016). Overall, the broader developmental aspiration of Solar PV is to support rural families in achieving a sustainable and dignified standard of living (IEA, 2025).

2.12 Productive Use Limitations and Community Alignment

Chirambo (2018) explored pathways for achieving Sustainable Development Goal 7 in Sub-Saharan Africa and stressed the need to align renewable energy initiatives, climate finance, and development programmes to expand access to modern energy services. While Solar PV integration with agricultural and economic activities offers potential benefits, such as food security, climate resilience, and gender equity, its ability to power income generating initiatives at scale is still limited (Chirambo, 2018). The capacity of SHS to support productive uses remains insufficient, especially for higher-load appliances required in agro-processing or business operations (Leonhardt et al., 2022; Peters et al., 2019). Financial barriers further constrain demand, with many rural households unable to afford Solar PV systems despite their interest in clean energy solutions (Blimpo et al., 2020; Vanadzina et al., 2019).

A key concern is the persistent disconnect between energy suppliers and local community priorities. While public and private actors promote Solar PV systems, many fail to deeply engage with communities to understand their specific energy aspirations and socio-economic realities (Batidzirai et al., 2021b). The absence of community aligned design has contributed to low uptake rates and underperformance of installed systems. Therefore, achieving meaningful progress in rural electrification depends on inclusive models that prioritise local engagement from conception to implementation, ensuring energy solutions align with rural livelihood strategies.

2.13 Summary and Implications for the Research

This chapter has reviewed the principal academic and policy debates surrounding rural energy poverty, Solar PV adoption, financing constraints, community participation, and the socio environmental impacts of decentralised renewable energy deployment in Sub- Saharan Africa. The literature demonstrates that, while Solar PV holds significant technical and environmental promise, its effectiveness in rural contexts is constrained by inadequate financing models, weak community engagement, poor alignment with livelihood priorities, and limited institutional capacity. The review has revealed several critical gaps that directly inform the present study. First, there is limited empirical research that captures the lived experiences and decision-making processes of rural solar users. Second, there is insufficient integration of environmental trade-offs, particularly the relationship between solar adoption and biomass based livelihood strategies such as charcoal production and non-timber forest product harvesting. Third, the literature offers inadequate attention to informal market actors, counterfeit technologies, and the emerging challenge of rural solar electronic waste. These gaps justify the focus of this thesis and directly shape its research aim, objectives, and questions. By applying the Rural Development Stakeholder Hybrid Adoption Model and generating primary qualitative data from rural Zambia, this study seeks to advance more grounded and policy relevant insight into how decentralised solar transitions can be made socially equitable, environmentally sustainable, and locally governed.

Chapter 3: Theoretical Framework

3.1 Introduction

This study employs the Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM) (Chanda et al., 2025a, 2025b, 2025c, 2025d, 2025g, 2025e, 2026) to provide a comprehensive understanding of the social, behavioural, environmental, and institutional factors shaping the adoption of solar photovoltaic (PV) systems in rural Zambia (see Fig. 1). Developed for this research, RUDSHAM integrates and adapts key constructs from four major theoretical models: the Technology Acceptance Model (TAM), the Theory of Planned Behaviour (TPB), Diffusion of Innovations (DoI) theory, and Social Learning Theory (SLT). Together, these form a multi-dimensional conceptual lens capable of accounting for both individual-level motivations and broader community-level influences that drive or constrain energy transitions in off-grid Sub-Saharan contexts.

The Rural Development Stakeholder Hybrid Adoption Model framework is uniquely suited to this thesis by publication format because it provides a coherent theoretical structure across all seven articles, each of which examines a critical dimension of Zambia's decentralised energy transition. These dimensions include informal charcoal economies, understood in this study as unregulated and community-based systems of charcoal production and trade that operate largely outside formal taxation and environmental oversight, and solar e-waste (electronic waste), defined as damaged, obsolete, or discarded solar photovoltaic components that are disposed of through informal practices such as open burning, burial, or unsafe household storage. The framework also captures livelihood integration, conceptualised in this study as the ways in which solar photovoltaic technologies are embedded within everyday rural survival and income generating strategies, including small scale trading, agricultural processing, and the harvesting of non-timber forest products. By bridging psychological, sociological, and policy perspectives, RUDSHAM supports a holistic analysis of the central questions of this thesis regarding what drives solar photovoltaic adoption in rural Zambia, whose actions shape these processes, and what barriers continue to constrain sustainable and inclusive energy futures.

3.2 Integrating Theories into RUDSHAM

3.2.1 Technology Acceptance Model (TAM)

TAM posits that individuals' adoption of a technology is influenced primarily by two beliefs: Perceived Usefulness (PU) and Perceived Ease of Use (PE) (Davis, 1989; Venkatesh and Davis, 2000). Within this study, PU includes the solar PV system's ability to support energy security, reduce reliance on biomass, and enable income-generating activities. PE refers to system simplicity including how easily solar technologies can be installed, maintained, and understood. These constructs are key in Articles 3, 6, and 7, where community members assessed the practicality of solar

PV in replacing charcoal and enhancing livelihood resilience, including in wild food harvesting, traditional brewing, and night time productivity.

3.2.2 Theory of Planned Behaviour (TPB)

TPB (Ajzen, 1991) offers insight into how attitudes, subjective norms, and perceived behavioural control (PBC) shape intentions and actions. In rural Zambia, adoption decisions are often influenced by perceived agency - whether individuals believe they have control over acquiring and maintaining solar technologies. This component is especially critical in Articles 4 and 5, which examine challenges such as counterfeit products, absence of warranties, and limited technical literacy, all of which diminish perceived control and reduce willingness to adopt solar PV systems.

3.2.3 Diffusion of Innovations (DoI)

DoI theory (Rogers, 2003a) explains how new technologies spread through societies via communication channels, social systems, and perceived advantages. In rural contexts, early adopters and community influencers act as critical intermediaries. Solar PV dissemination in Zambia is rarely linear or state led. It relies heavily on informal learning and peer demonstration. Articles 2 and 3 deploy DoI principles to understand how uptake occurs through neighbour influence and trusted social networks, especially in communities where literacy rates are low and formal marketing is absent.

3.2.4 Social Learning Theory (SLT)

SLT (Bandura, 1977) provides the foundation for understanding how individuals learn through observing and interacting with others. It emphasises modelling, reinforcement, and social imitation, making it highly relevant to rural adoption processes shaped by shared practices and community experiences. SLT directly supports Articles 1 and 3, which explore the role of peer influence and informal leadership in shaping energy behaviour, particularly in the context of socialised charcoal production and neighbour-driven solar adoption.

3.2 Theoretical Integration and Limitations

The construction of RUDSHAM as a hybrid framework raises important concerns about combining elements from distinct theoretical traditions. Critics argue that unreflective integration can lead to conceptual redundancy, loss of theoretical clarity, or internal inconsistency if constructs are merged without attention to their original assumptions and domains of application. In developing RUDSHAM, these concerns were addressed through a deliberate process of selection, refinement, and boundary setting. First, only constructs that directly illuminate rural solar adoption in Zambia were retained, and overlapping concepts were consolidated under clearly defined attributes. Second, the relationships between psychological, social, institutional, and environmental dimensions were specified at the level of heuristic guidance rather than strict causal claims, thereby avoiding false precision. Third, RUDSHAM is presented as an applied analytical framework rather than a universal theory.

3.3 Conceptualising RUDSHAM for Energy Transitions

RUDSHAM synthesises the theories above into a single, applied framework appropriate for multi-scalar, community-based inquiry. It accounts for both internal drivers of adoption (such as perceived usefulness, confidence, and cost), and external influences (including social norms, policy support, and community leadership). The framework also integrates unique rural development considerations like community participation, livelihood integration, and environmental consciousness. This hybrid approach enables a more nuanced understanding of how decentralised energy systems function in places like rural Zambia, where formal infrastructure is sparse, but social structures are strong and deeply embedded.

3.4 RUDSHAM Informing Methodology

The empirical research underpinning this thesis relied on in-depth interviews, focus group discussions, and participant observation across four districts. Guided by RUDSHAM, data collection and analysis were structured around ten attributes, each representing a key dimension of solar PV adoption. These dimensions were operationalised during fieldwork and mapped onto the research questions and article themes.

3.5 RUDSHAM Attributes and Their Application

3.5.1 Perceived Ease (PE)

This attribute assesses how intuitive and user-friendly solar PV systems are for rural adopters. Data focused on installation challenges, maintenance burdens, and the availability of technical assistance. Respondents reported that while installation was often straightforward, maintenance and battery replacement posed significant difficulties due to cost and limited technical support. Linked to Articles 3, 4, 6.

3.5.2 Perceived Usefulness (PU)

PU encompasses the extent to which solar PV is seen as effective, reliable, and capable of improving living standards. Evidence showed that users valued lighting, refrigeration, and phone charging. PV systems enabled longer business hours, better study conditions for children, and improved wild food storage. Linked to Articles 3, 6, 7.

3.5.3 Norms (NO)

This refers to the influence of community expectations, household roles, and cultural norms. Observational learning was found to be crucial. People were more likely to adopt if their neighbours had done so successfully. Women’s roles in energy use and decisions were particularly relevant in influencing adoption within households. Linked to Articles 3, 4.

3.5.4 Perceived Behavioural Control (PBC)

This dimension evaluates the extent to which rural consumers feel they can make informed, autonomous decisions. Lack of warranties, information asymmetry, and prevalence of counterfeit solar products all contributed to low confidence in technology markets. Linked to Articles 4, 5.

3.5.5 Policy Support (PS)

This attribute considers governmental and institutional involvement in promoting decentralised energy. Findings revealed a policy practice gap: while solar PV features in national development plans, implementation was weak, especially in remote regions. Participants reported minimal interaction with policy actors or awareness of available subsidies. Linked to Articles 1, 4, 5.

3.5.6 Economic Cost (EC)

Here, attention was paid to affordability, payment models (e.g. pay-as-you-go), and financial risk. Households appreciated the long-term cost savings of solar PV but struggled with initial capital. Alternative finance models like micro-loans or group savings were more attractive but not always available. Linked to Articles 2, 5, 6.

3.5.7 Community Participation (CoP)

This captures the extent to which communities are involved in the design, financing, and long-term management of solar PV systems. Sites where communities co-financed systems or had a say in product choice showed better maintenance and trust in the systems. Linked to Articles 5, 6, 7.

3.5.8 Prior Preferences and Practice (PP)

This dimension captures historical energy behaviours, particularly the reliance on biomass, such as charcoal and firewood. While solar PV was welcomed for lighting and small appliances, households remained attached to charcoal for cooking, due to cost, convenience, and cultural preferences. Linked to Articles 1, 2.

3.5.9 Green Concern (GC)

This attribute gauges environmental awareness and the degree to which sustainability considerations shape energy choices. Respondents expressed concern over deforestation, especially in charcoal producing areas. However, environmental concern was a secondary motivator behind adoption as livelihood improvement and reliability came first. Linked to Articles 2, 6, 7.

3.5.10 Financial Models of Relevance (FMR)

This element examines how solar PV systems are financed, and whether global models (e.g. PAYG, leasing) are suitable in local contexts. Findings suggest that while PAYG is popular, it is prone to system failure, poor after-sales support, and lock out risks. Community-led finance models showed promise. Linked to Articles 5, 6.

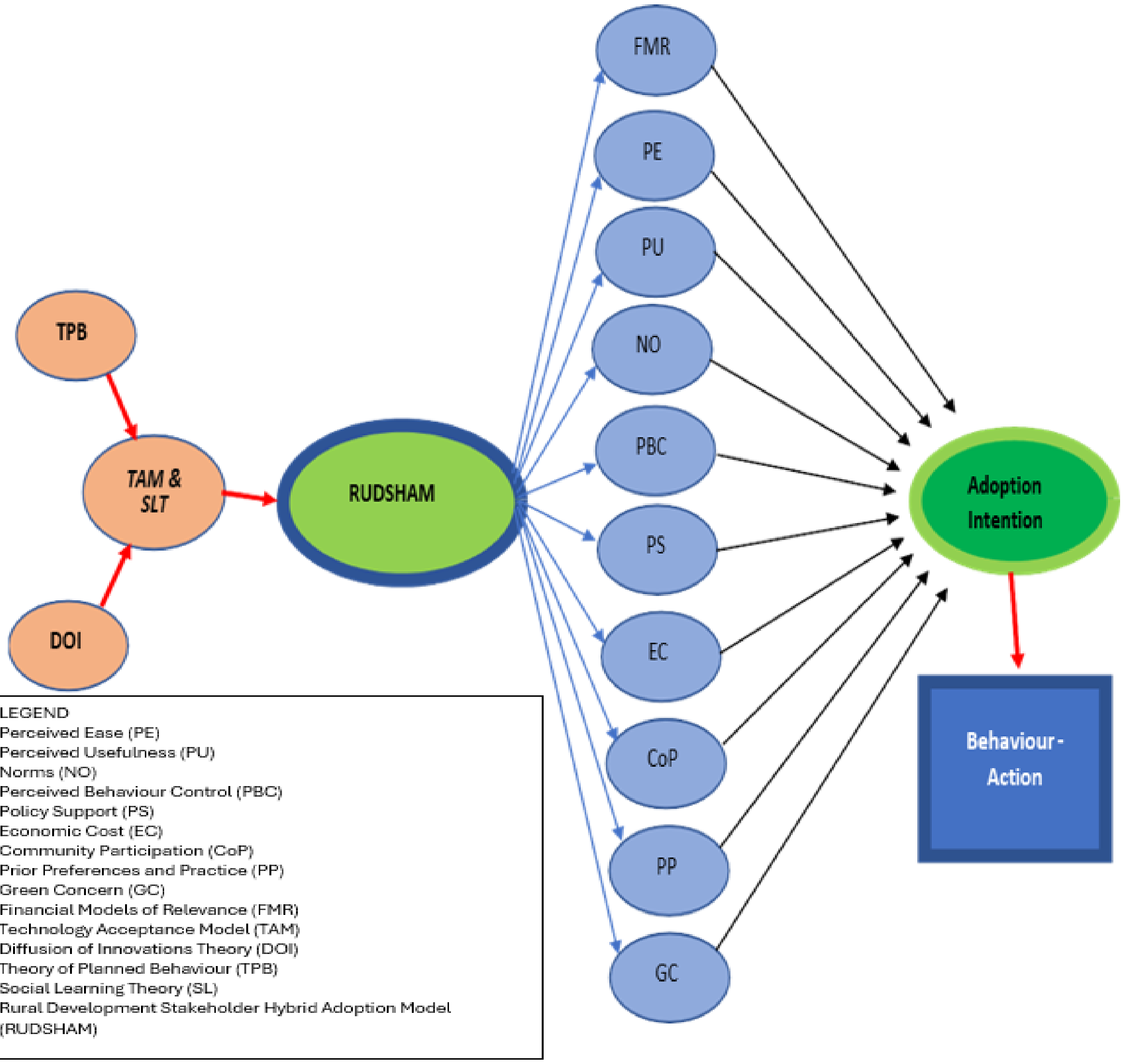

Figure 1: RUDSHAM Hybrid Adoption Model

3.6 RUDSHAM's Contribution to Theory and Practice

The RUDSHAM framework has enabled this study to bridge theory and practice, offering a grounded yet comprehensive understanding of rural energy adoption. It aligns with the thesis aim to investigate how solar PV adoption in rural Zambia is shaped by community needs, environmental trade-offs, and informal actors, and speaks directly to each research objective:

- Environmental trade-offs (PP, GC, EC)
- Community learning and social dynamics (NO, CoP, SLT)
- Lifecycle and quality management (PE, PBC, PU)
- Non-traditional energy actors (PS, FMR, CoP)
- Livelihood integration (PU, GC, CoP)

As Zambia and other African countries pursue clean energy pathways under the Sustainable Development Goals (particularly SDG 7), RUDSHAM offers a valuable framework for policy formulation, community engagement, and project evaluation. Its capacity to integrate diverse dimensions, technical, behavioural, economic, and social, makes it adaptable across different decentralised energy contexts beyond Zambia.

Chapter 4: Research Methodology

4.1 Overview and Methodological Framing

This thesis draws on an integrated methodological framework that guided the development of seven interlinked, articles, unified by the overarching aim of understanding how solar PV adoption and management unfold in rural Zambia within the broader context of Sub-Saharan Africa's energy transition. Anchored in qualitative inquiry and community-based participatory approaches, the methodology was designed to explore the multi-dimensional and place-specific dynamics of decentralised energy transitions so as to emphasise social learning, informal energy governance, environmental trade-offs, and livelihood integration. Guided by the RUDSHAM framework (Chanda et al., 2025a, 2025b, 2025c, 2025g, 2025e, 2025d, 2026), the research engaged with multiple actors, including households, informal traders, charcoal producers, commercial farmers, and local leaders, through interviews, focus group discussions (FGDs), and ethnographic observation. The fieldwork supports the specific thematic inquiries pursued in the following **seven articles all published in Q1 journals**:

Article 1: "Energy transitions in Sub-Saharan Africa: Policy recommendations for charcoal trade, solar PV adoption, and sustainability in rural Zambia" (Published in Energy Policy Journal: https://doi.org/10.1016/j.enpol.2025.114936)

Article 2: "The African clean energy-deforestation paradox: Examining the sustainability trade-offs of rural solar energy expansion in Zambia" (Published in Energy Research & Social Sciences Journal: https://doi.org/10.1016/j.erss.2025.104389)

Article 3: "Community-Led Solar Energy Technology Adoption in Rural Zambia: The Role of Observational Learning and Neighbour Influence." (Published in Energy Research & Social Sciences Journal: https://doi.org/10.1016/j.erss.2025.103972)

Article 4: "The solar E-waste challenge: A Zambian case study of informal disposal, counterfeit technologies and low literacy" (Published in Journal of Environmental Management: https://doi.org/10.1016/j.jenvman.2025.127618)

Article 5: "Exploring the nexus of solar adoption, sustainability, and rural community development through the role of White commercial farmers: The case of Mkushi, Zambia" (Published in Energy Research & Social Sciences Journal: https://doi.org/10.1016/j.erss.2025.104336)

Article 6: "Nexus Between Solar-PV Adoption and Wild Food Sustainability: Case of Income from Honey, Fruits, Traditional-Beer, and Vegetables in Rural Zambia"

(Published in Energy for Sustainable Development Journal: https://doi.org/10.1016/j.esd.2025.101694)

Article 7: “Environmental and social impacts of self-financed solar PV adoption in rural Zambia: Insights from mopane worms, mushrooms, fishing, bushmeat and ethnomedicine” (Published in Energy for Sustainable Development Journal: https://doi.org/10.1016/j.esd.2025.101665)

These articles collectively respond to the central problem statement and research questions by drawing on empirical data from targeted communities.

4.1.1 Articles and Research Objectives Alignment Descriptive Map

Article 1, Energy transitions in Sub-Saharan Africa: Policy recommendations for charcoal trade, solar PV adoption, and sustainability in rural Zambia, directly addresses Research Objective 1 by examining the interaction between solar PV expansion, charcoal dependence, deforestation, and national energy policy.

Article 2, The African clean energy deforestation paradox: Examining the sustainability trade-offs of rural solar energy expansion in Zambia, also primarily addresses Research Objective 1, with a particular focus on environmental trade-offs and the paradoxical financing of clean energy through ecologically damaging practices.

Article 3, Community Led Solar Energy Technology Adoption in Rural Zambia: The Role of Observational Learning and Neighbour Influence, directly addresses Research Objective 2 by analysing social learning, peer influence, and community driven pathways of adoption and sustainability.

Article 4, The solar E-waste challenge: A Zambian case study of informal disposal, counterfeit technologies and low literacy, directly addresses Research Objective 3 by examining lifecycle management challenges, informal disposal practices, and the circulation of substandard technologies.

Article 5, Exploring the nexus of solar adoption, sustainability, and rural community development through the role of White commercial farmers: The case of Mkushi, Zambia, directly addresses Research Objective 4 by investigating the role of non-traditional actors in facilitating or constraining solar access and infrastructure development.

Article 6, Nexus Between Solar PV Adoption and Wild Food Sustainability: Case of Income from Honey, Fruits, Traditional Beer, and Vegetables in Rural Zambia, directly addresses Research Objective 5 by examining livelihood interactions between solar adoption and non-timber forest product based income.

Article 7, Environmental and social impacts of self financed solar PV adoption in rural Zambia: Insights from mopane worms, mushrooms, fishing, bushmeat and ethnomedicine, also addresses Research Objective 5 by analysing the broader environmental and social livelihood effects of solar adoption in rural contexts.

4.2 Study Sites and Justification

Fieldwork was conducted over a 30-month period (October 2022 - May 2025) across four purposively selected rural districts in Zambia: Mkushi Rural and Kapiri Rural (Central Province), Chongwe Rural (Lusaka Province), and Chingola Rural - Luano (Copperbelt Province) (see Fig. 2). These sites were strategically selected based on:

- High rates of off-grid solar PV penetration;
- Informal energy market prevalence, particularly in solar and charcoal trade;
- Absence of formal e-waste management infrastructure;
- Socio-economic vulnerabilities and low literacy levels;
- Cultural and ecological diversity relevant to wild food harvesting and sustainable livelihoods.
- Mkushi was further selected for its high concentration of White commercial farmers, enabling investigation of their role in shaping rural solar transitions.
- Luano district provided insight into charcoal production and its intersection with solar adoption.

Each site thus contributes contextually specific insights to the objectives of individual articles, while collectively enriching the thesis's broader inquiry into the environmental, social, and behavioural dimensions of energy transitions.

4.3 Sampling Strategy

A multi-stage, non-probability sampling approach was employed. In the first stage, study locations were selected purposively based on key geographical and socio-technical characteristics aligned with the research objectives. In the second stage, participants were selected through purposive, snowball, and convenience sampling, targeting key groups:

- Households using solar PV technologies (Article 3, 4, 6, 7)
- Full-time charcoal producers (Article 1, 2)
- Commercial farmers, especially white-owned (Article 5)
- Solar energy companies and policy officials (Articles 1, 4)
- Rural entrepreneurs and forest product harvesters (Articles 6, 7)

A four week pilot study was conducted in Luano (Chingola Rural) with five participants to pre-test instruments, refine language, and ensure cultural and contextual relevance.

One local key informant in each site facilitated community entry, participant recruitment, and scheduling. A multilingual research assistant fluent in Bemba, Tonga, Soli, Lamba, and Nyanja supported data collection, alongside the principal investigator, who has working knowledge of Bemba, Nyanja, and Lamba.

4.4 Data Collection Methods

The study employed a mix of in-depth interviews (IDIs), focus group discussions (FGDs), and participant observation. These methods facilitated detailed exploration of solar adoption practices, environmental trade-offs, and informal energy governance.

Interviews:
A total of 108 IDIs were conducted across the four study areas, broken down as follows:

- 21 interviews with full-time charcoal burners to explore biomass dependence and charcoal-solar dynamics (Articles 1, 2)
- 40 interviews with rural smallholder farmers on adoption behaviour, motivations, and livelihood integration (Articles 3, 6,7)
- 16 interviews with commercial farmers (including White commercial farmers in Mkushi) exploring their role as solar adopters, financiers, and influencers (Article 5)
- 28 interviews with households and rural businesses already using solar PV, focusing on perceptions, product quality, experiences with counterfeit products, maintenance challenges, and disposal behaviour (Articles 3, 4, 6,7)
- 3 interviews with solar company representatives and policymakers to capture sectoral insights on regulation, support mechanisms, and e-waste challenges (Articles 1, 4)

Interviews lasted between 30 and 60 minutes and were conducted in participants' preferred languages, often in situ to enhance contextual depth.

Focus Group Discussions (FGDs):
A total of 12 FGDs were held, in four distinct provinces across Zambia. These are:

- 4 in Kapiri
- 3 in Mkushi
- 3 in Chongwe
- 2 in Luano

Each FGD included 7 to 12 participants, providing space for community validation, shared reflections, and group learning dynamics. Three FGDs were dedicated to charcoal producers and structured to ensure inclusive dialogue and reduce dominance effects. The FGDs enriched findings for the Articles by capturing group level perceptions and communal energy decisions.

Participants received refreshments and small tokens of appreciation, in accordance with ethical standards and local cultural expectations. These resources were provided by the researchers; however, the refreshments were prepared by key informants and trusted local community members. Additionally, the research team was advised to visibly partake in the refreshments they brought, as a gesture to build trust, demonstrate cultural sensitivity, and reassure participants of the safety and good faith behind the offerings.

4.5 Data Management and Analytical Framework

All data (audio recordings, photographs, and video clips) were securely stored on the University of Reading's encrypted OneDrive platform, accessible only to the research team. Interviews and FGDs were transcribed and, where necessary, translated into English.

The data was analysed using NVIVO 14, following a thematic approach structured around the RUDSHAM framework. Colour coded coding schemes and NVIVO's advanced tools (e.g., query matrices, node classification) were used to identify cross cutting patterns across sites and participant types.

This analytical structure allowed for iterative, grounded theorisation that connected empirical findings directly to the thesis objectives and each article's specific research focus.

4.6 Gender Sensitivity and Ethical Considerations

Ethical approval was obtained from the University of Reading's Research Ethics Committee. Informed consent was secured from all participants through oral and written explanations in appropriate languages. Interviews and FGDs were conducted with sensitivity to power dynamics, gendered spaces, and participant privacy.
Gender sensitive practices included:

- Creating safe spaces for women to freely express themselves during interviews and focus group discussions (FGDs), particularly on issues affecting them such as domestic energy use, gender biases, and equity in energy access;
- Ensuring that women's voices were not overshadowed in mixed gender groups, with deliberate facilitation strategies to encourage balanced participation;
- Engaging facilitators who were known and trusted by the community to minimise discomfort and enhance open dialogue.

To maintain confidentiality, all identifying information was anonymised during transcription. Data access remains restricted to authorised research personnel.

4.7 Methodological Contribution to the Thesis Aim

This methodology provided a robust empirical foundation for addressing the thesis's core aim: to examine how solar PV adoption and management in rural Zambia is shaped by community needs, environmental trade-offs, and informal actors within the broader energy transition. Each methodological component was tailored to address specific research objectives and article themes as follows:

- Articles 1 and 2 employed data from charcoal producers, policy actors, and rural households to explore biomass dependence and sustainability tensions.
- Articles 3 and 5 drew on household interviews and community interactions to examine informal learning, neighbour influence, and the role of White commercial farmers.
- Article 4 centred on lifecycle challenges, informal disposal, and the proliferation of counterfeit solar products.
- Articles 6 and 7 leveraged interviews with rural entrepreneurs and natural product harvesters to assess livelihood synergies between solar energy and wild food sustainability.

By integrating diverse data sources, regional variations, and community-grounded perspectives, this methodology enabled the production of rich, policy-relevant insights into decentralised solar adoption across Zambia’s rural landscape.

4.8 Integration of RUDSHAM in the Case Study Design

The Rural Development Stakeholder Hybrid Adoption Model provided the analytical lens through which the case study was designed and operationalised across all seven articles. First, RUDSHAM informed site selection by foregrounding the interaction between behavioural, institutional, environmental and livelihood dimensions, leading to the inclusion of locations characterised by charcoal economies, informal solar markets and wild food dependence. Second, it guided sampling by ensuring that stakeholder categories reflected in the framework, including households, charcoal producers, White commercial farmers, informal traders and policy actors, were represented. Third, the framework shaped the structure of interview and focus group guides, which were organised around RUDSHAM domains such as social learning processes, informal governance, technology reliability and livelihood integration. Finally, data analysis in NVIVO was coded against the core elements of the framework, with nodes and themes corresponding to its components. In this way, each article represents a focused application of RUDSHAM to a subset of the framework, while the thesis demonstrates how the framework can be used to integrate multi actor, multi scalar evidence on rural solar adoption in systematic form in Zambia.

Figure 2: Map of Zambia (UN 2022)

4.9 Overview of Articles

Collectively, the seven articles in this thesis interrogate the multidimensional dynamics of solar photovoltaic (PV) adoption in rural Zambia, fulfilling the overarching aim to examine how adoption is shaped by community needs, environmental trade-offs, and informal actors. Articles 1 and 2 address Objective 1, unveiling the paradox wherein charcoal and forest-based income fuels solar transitions, thereby highlighting environmental tensions. Articles 3 and 4 engage with Objectives 2 and 3 by exploring social learning pathways and revealing critical challenges related to solar e-waste and product reliability. Article 5 addresses Objective 4, uncovering the contributions of non-traditional actors, particularly White commercial farmers, in advancing rural solar access and infrastructure. Articles 6 and 7 engage Objective 5 by analysing the socio-environmental impacts of self-financed solar PV systems through edible and non-edible non-timber forest products. Each article builds contextually and thematically, collectively offering an empirically grounded understanding of Zambia's rural energy transition. This integrated, publication-based approach affirms the complexity of solar PV adoption and calls for policies that are socially inclusive, environmentally sustainable, and locally embedded.

Please note that all articles are presented as submitted to academic journals, as a result several sections will be repeated across each article, for example, methodology and theory etc. The content will in large part be repetitious but with minor adjustments specific to the research article.

Chapter 5: Energy transitions in Sub-Saharan Africa: Policy recommendations for charcoal trade, solar PV adoption, and sustainability in rural Zambia. (Article 1)

Status: Published - Energy Policy Journal (https://doi.org/10.1016/j.enpol.2025.114936)

Summary: The insights from this article reveal how Zambia's rural households navigate energy poverty through environmentally destructive practices, highlighting a fundamental paradox between charcoal production and solar PV adoption. While this trade-off is driven by necessity, it calls attention to broader sustainability challenges in energy transitions. Building on this, the next article delves deeper into the clean energy-deforestation paradox, critically examining how forest degradation is often unintentionally financed by solar uptake and explores the urgent need for integrated environmental and energy governance in rural Zambia.

Abstract: This article interrogates the complex relationship between charcoal trade and solar PV adoption in rural Zambia. It reveals a paradox in which charcoal income, derived from environmentally harmful practices, funds basic solar technologies. Yet, this pathway is economically and ecologically unsustainable. Urban charcoal demand, not rural consumption, is the primary deforestation driver, making rural bans largely ineffective. The study introduces the "Forest-to-Solar Economic Trade-Off Ratio", estimating that 20 trees are needed to generate the income for a $52 solar system. Gender disparities further exacerbate the issue, as women are disadvantaged within the charcoal economy.

Key recommendations: Recommendations include subsidising clean urban energy access, expanding solar microfinance schemes, and enforcing sustainable forestry regulations.

Objectives alignment: By highlighting these contradictions, the article directly addresses Thesis Objectives 1 and 5, exposing the environmental trade-offs of Zambia's rural energy transition.

Overall contribution: This article significantly contributes to the broader thesis by framing energy transitions not as linear progressions, but as embedded economic compromises. It situates environmental degradation within the lived realities of energy poverty, providing a foundation for the RUDSHAM framework's application.

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Keywords: Rural Energy Transition, Charcoal Trade, Solar PV, Sustainability, Policy, Deforestation

5.1 Introduction and Background

Sub-Saharan Africa (SSA) faces a critical energy paradox: while the region possesses vast renewable energy potential, including abundant solar resources, its populations remain heavily dependent on traditional biomass fuels such as charcoal and firewood for basic energy needs (Kaoma and Gheewala, 2020). In Zambia, this contradiction is acutely evident. Approximately 98% of rural households rely on biomass as their primary energy source, with charcoal remaining the dominant fuel despite its well documented environmental and public health consequences (Kaoma and Gheewala, 2020). The continued use of charcoal is not solely a cultural or habitual phenomenon; rather, it reflects structural energy poverty and persistent policy limitations that restrict access to viable clean energy alternatives such as solar photovoltaic (PV) technologies (Chambalile et al., 2024; Tomala et al., 2021).

Globally, reliance on biomass contributes significantly to household air pollution (HAP), which is associated with respiratory and cardiovascular illnesses. Approximately four million premature deaths annually are linked to exposure to HAP (Clean Cooking Alliance, 2025). Children under the age of five are particularly affected, with over 700,000 deaths attributed to air pollution in 2021 alone (State of Global Air, 2024). Within SSA, the health burden is disproportionately high due to poor ventilation, limited health infrastructure, and entrenched energy practices (Roomaney et al., 2022; Simkovich et al., 2019).

Evidence from Zambia reinforces these concerns. Over 80% of Zambians rely on wood fuel for cooking, often using inefficient traditional stoves that exacerbate health risks (Makai and Molinas, 2013). Exposure to HAP has been associated with perinatal mortality, including stillbirths and early neonatal deaths (Patel et al., 2016). In rural Zambian households using biomass, high concentrations of indoor particulate matter and volatile organic compounds have been linked to respiratory problems and impaired lung function (Mulenga and Siziya, 2019). These findings align with broader regional trends observed in countries such as Nepal and South Africa, where household air pollution has similarly been linked to increased rates of childhood pneumonia, chronic obstructive pulmonary disease (COPD), and cardiovascular illness (Roomaney et al., 2022; Shrestha, 2022).

Zambia's energy system also grapples with structural challenges. Although hydropower remains the primary source of electricity generation, its capacity is limited and increasingly vulnerable to climate variability (Malange et al., 2021; Munyeme, G., Jain, 1994). In response, solar PV has emerged as a promising solution due to Zambia's high annual solar irradiation, averaging 5.5 kWh/m^2 (Makai and Chowdhury, 2017). Nonetheless, the transition to solar PV remains limited in scope due to prohibitively high upfront costs, lack of consumer education, and underdeveloped market frameworks (Chambalile et al., 2024; Mfune and Boon, 2008). This juxtaposition emphasises the broader energy transition dilemma in SSA: the need to accelerate the uptake of clean energy technologies while addressing the socioeconomic realities that perpetuate reliance on traditional fuels.

Against this backdrop, this chapter explores the policy implications of charcoal trade and solar PV adoption in rural Zambia. It critically examines how policy frameworks can be restructured to address environmental degradation, energy inequality, and public health outcomes simultaneously. By drawing on interdisciplinary evidence, the study contributes to ongoing discourse on just energy transitions, aiming to provide actionable insights for policymakers working to balance sustainability, affordability, and equity in SSA's evolving energy landscape.

5.1.1 Charcoal's Socio-Economic and Environmental Role

Charcoal production is a significant livelihood strategy in rural Zambia, with 32% of household income among non-timber forest product (NTFP) dependent households derived from charcoal trade (Chanda et al., 2025b; Steel et al., 2022). Furthermore, 68% of NTFP dependent households engage in charcoal and firewood sales, underlining the trade's importance for poverty alleviation (Mulenga et al., 2014; Steel et al., 2022). As urban demand for charcoal continues to rise, rural producers find it an accessible and profitable venture despite its environmental consequences. The expansion of charcoal production has drastically altered Zambia's forest landscapes. Between 2010 and 2020, charcoal production zones expanded from 190 km to 350 km from Lusaka, contributing to a 79.3% reduction in aboveground biomass and a 74.2% loss in tree cover in affected areas (Sedano et al., 2022). Zambia's deforestation rate, estimated at 180,000 to 250,000 hectares per year, is among the highest globally, with 25% of forest loss directly attributed to charcoal production (Nansikombi et al., 2020a; Phiri et al., 2019; USAID A2C, 2021). Deforestation driven by the charcoal trade leads to biodiversity loss, ecosystem degradation, and increased carbon emissions, exacerbating climate change (Nyarko et al., 2021; Rose et al., 2022).

Despite its economic benefits, the sector remains largely informal and unregulated, exacerbating inefficiencies. Over 98% of charcoal entering urban markets is unregulated and untaxed, leading to an estimated K2 billion in lost revenue annually (USAID A2C, 2024). Furthermore, many rural producers remain dependent on charcoal as their primary economic activity due to limited access to alternative livelihoods and clean energy sources (Kutsch et al., 2011). Without targeted interventions, the expansion of the charcoal industry will continue at the expense of Zambia's forests and rural economies.

5.1.2 Solar PV's Role and Barriers

As a renewable energy alternative, solar PV holds immense promise for rural electrification in Zambia. The country is endowed with vast solar resources, making decentralised solar PV systems, such as pay-as-you-go (PAYG) solar home systems and pico-scale PV installations, viable solutions for off-grid communities (Nygaard et al., 2016; Tinta et al., 2023). These innovations have already expanded electricity access in some rural areas, but adoption remains constrained by financial, infrastructural, and socio-cultural barriers (Chambalile et al., 2024; Mfune and Boon, 2008).

Economic constraints constitute one of the greatest barriers to solar PV expansion. The high upfront costs of solar PV systems, coupled with limited financing options, make it difficult for low income households to afford these technologies (Chidembo et al., 2022). While PAYG models provide a flexible payment approach, concerns about "energy lock-in", where households remain restricted to low capacity solar systems incapable of supporting higher energy demands, persist (Hassan et al., 2020). Hence many household are unable to use solar PV for productive purposes to raise income and improve their lives. Furthermore, households with higher income levels are more likely to invest in PV systems due to their perceived reliability and long-term economic benefits (Zulu et al., 2022).

Socio-cultural factors also shape household energy choices. Charcoal remains a preferred fuel due to its affordability, availability, and suitability for traditional cooking methods (Sadik-Zada et al., 2023). Gender dynamics further influence energy transitions, as women, who are typically responsible for cooking, face disproportionate health risks from indoor air pollution but often lack decision making power in energy purchases (Johnson et al., 2019).

5.1.3 Policy Gaps and Research Contribution

Despite increasing awareness of the urgent need for an integrated energy transition strategy, existing policies in Zambia remain fragmented and ineffective. Current frameworks prioritise renewable energy expansion and forest conservation separately, without adequately addressing the interconnections between charcoal dependency, energy poverty, and economic livelihoods. Policy interventions promoting improved carbonization techniques and sustainable forest management have also yielded limited results due to weak enforcement mechanisms (Gumbo et al., 2013; Veen et al., 2021). This lack of effective oversight has allowed unsustainable practices to persist, undermining efforts to reduce deforestation and transition to cleaner energy alternatives. This study seeks to bridge critical knowledge gaps by examining the intersection of charcoal trade, solar PV adoption, and sustainability in Zambia's rural energy landscape. Specifically, it aims to:

- Assess the socio-economic drivers of charcoal dependency and its implications for poverty alleviation and rural livelihoods.
- Evaluate the environmental consequences of charcoal production, including deforestation, biodiversity loss, and carbon emissions.
- Develop policy recommendations that integrate energy access, economic development, and environmental sustainability to support a just energy transition.

By situating energy transitions within localised contexts of poverty, informal markets, and policy incoherence, the research contributes to a deeper understanding of how integrated, context-sensitive strategies can advance sustainability goals in Sub-Saharan Africa's rural energy landscape.

5.2 Literature Review

5.2.1 Charcoal Production in Sub-Saharan Africa

Findings from prior research illustrate that charcoal remains a key energy source in Sub-Saharan Africa, with 195 million people relying on it as their primary fuel and an additional 200 million as a secondary source (Rose et al., 2022). However, its production drives environmental and health crises. Inefficient carbonization contributes to about 7% of global deforestation, releasing 71.2 million tonnes of CO_2 and 1.3 million tonnes of CH_4 annually, exacerbating climate change (Sakala et al., 2023). In Ghana, Ethiopia, and Somalia, unsustainable harvesting has led to extensive forest loss, mirroring Zambia's worsening deforestation (Arko et al., 2024; Gebremeskel, 2023; Kullane et al., 2022). Additionally, charcoal combustion elevates indoor carbon monoxide levels, increasing risks of poisoning, cognitive decline, and respiratory diseases such as chronic obstructive pulmonary disease (COPD), asthma, and tuberculosis (Dillon, 2021; McCord et al., 2024; Senya et al., 2018). Despite these dangers, public awareness remains low, emphasizing the urgency for targeted policy interventions (Idowu et al., 2023). Charcoal's persistent reliance across SSA highlights a regional crisis that blends energy poverty with health burdens, underlining the need for cohesive policy responses that move beyond localised accounts to systemic solutions.

5.2.2 Deforestation and Policy Gaps in Zambia

Extant literature identifies charcoal production as a key driver of deforestation in Zambia, contributing to 25% of annual forest loss, which ranges between 180,000 and 250,000 hectares (Nansikombi et al., 2020a; Tembo et al., 2015; USAID A2C, 2021). Unlike agricultural expansion, which can result in cropland use, charcoal driven deforestation is often followed by long-term land degradation, with less than 25% of cleared areas cultivated within seven years (Sedano et al., 2022). This process diminishes soil fertility, biodiversity, and carbon sequestration. Additionally, weak enforcement mechanisms allow illegal charcoal production to persist even in protected areas, further undermining conservation efforts (Sedano et al., 2022; Silva et al., 2019). Contrastingly, other literature postulates that agricultural expansion is a more significant contributor to deforestation, accounting for nearly 90% of Zambia's forest cover loss (Kabisa et al., 2019; Mabeta et al., 2018). Between 2000 and 2018, cropland expanded by 25%, leading to a 10% decline in forest cover (Phiri et al., 2022). Smallholder farmers, responsible for 60% of this loss, clear forests due to declining soil fertility, encroaching into an average of 0.10 hectares per household annually (Ngoma et al., 2021). The Miombo ecoregion, covering 45% of Zambia, experiences the highest deforestation rates from both agricultural expansion and charcoal production (Nansikombi et al., 2020a). Despite these competing perspectives, weak land governance and poor enforcement remain central to Zambia's deforestation crisis (Kabisa et al., 2019; Moombe et al., 2020). Given the Miombo woodlands' role in biodiversity conservation and carbon sequestration, sustainable interventions such as improved land-use regulations and soil restoration programmes are crucial (Handavu et al., 2019). The contrasting perspectives seem to arise from differing methodological focuses with some studies isolating charcoal's localised impact, while others assess broader national trends dominated by agriculture. Both, however, reveal policy and enforcement weaknesses as core drivers. While this section centres Zambia, similar governance gaps affect forest management across SSA, demonstrating a need for comparative studies and harmonised policy approaches to address charcoal induced degradation regionally.

5.2.3 Charcoal and Solar Energy Dilemma

Empirical evidence indicates that despite the environmental and health risks associated with charcoal, Zambia's energy transition remains sluggish. Solar photovoltaic (PV) technology is a viable alternative, yet its widespread adoption is impeded by high initial costs, limited financing, and infrastructural deficiencies (Chambalile et al., 2024). While off-grid solar systems have been introduced, their impact on reducing charcoal dependency remains limited, as biomass continues to dominate household energy consumption for cooking (Nygaard et al., 2016; Tinta et al., 2023). Interestingly, other scholars postulate that income from charcoal production has facilitated solar PV adoption in some rural communities, as earnings are reinvested in solar home systems and pico-solar devices, mainly for lighting and phone charging (Nygaard et al., 2016). This presents a contradictory dynamic where charcoal both contributes to deforestation and enables renewable energy uptake (Tinta et al., 2023). However, without stronger financial incentives and policy interventions, solar adoption will remain constrained, reinforcing biomass reliance (Chambalile et al., 2024). Extant literature highlights that Zambia's high solar potential could significantly reduce biomass reliance and lower CO_2 emissions (Aboagye and Adjei Kwakwa, 2023; Byaro et al., 2024; Chanda et al., 2025a). Conversely, while some scholars argue that charcoal-generated income is actively financing small scale solar adoption in SSA (Chanda et al., 2025b), others emphasise that the prohibitive cost of productive-use solar systems restricts broader adoption (Tinta et al., 2023). This stresses the need for targeted financial mechanisms to accelerate Zambia's energy transition (Chambalile et al., 2024). This connection of biomass dependency and renewable uptake reflects a wider SSA pattern, demanding integrated policy responses that recognise charcoal's economic utility while promoting scalable clean energy solutions.

5.2.4 Charcoal's Economic Role in Zambia

Existing research indicates that charcoal production remains a key economic activity in Zambia, providing income for rural households, particularly in regions with limited employment opportunities (Wang et al., 2022). Non-timber forest products (NTFPs), including charcoal, contribute up to 32% of total rural income (Chanda et al., 2025b; Mulenga et al., 2014; Steel et al., 2022). While its economic significance is undeniable, unsustainable harvesting has resulted in extensive deforestation and land degradation, with miombo woodlands experiencing severe biomass depletion (Gumbo et al., 2013; Kutsch et al., 2011). Nationally, 68% of NTFP dependent households rely on charcoal and firewood sales, reinforcing the "charcoal trap," where the absence of viable energy alternatives perpetuates reliance on wood fuel (Kutsch et al., 2011). To mitigate these effects, policymakers have introduced forest regeneration programmes and promoted alternative NTFPs, such as wild honey and mushrooms, as sustainable income sources to reduce charcoal dependence while balancing rural livelihoods and conservation (Chanda et al., 2025b; Wang et al., 2022). Extant literature emphasises charcoal's dual function as both energy and income source, making it vital for policy design to balance environmental limits with rural livelihood imperatives across the SSA region.

5.2.5 Health Impacts from Charcoal Use

Scholarly discourse emphasises the severe health risks associated with charcoal burning in Zambia, particularly chronic respiratory diseases such as COPD (Fullerton et al., 2011). Biomass fuel users experience lung function deterioration, with exposure levels exceeding World Health Organization (WHO) thresholds (Dillon, 2021). Poorly ventilated homes intensify the dangers, as charcoal combustion releases high concentrations of particulate matter (PM), carbon monoxide (CO), and volatile organic compounds (VOCs) (Iqbal and Kim, 2016; Mencarelli et al., 2023). Women and children are disproportionately affected due to prolonged exposure (Balmes, 2015; Kirubi, 2004). Scholars propose clean cooking technologies, liquefied petroleum gas (LPG), and biogas as viable interventions (Makai and Molinas, 2013). While evidence on health impacts is robust, policy focused literature remains limited; more emphasis is needed on translating these risks into enforceable and context-specific interventions across SSA households.

5.2.6 Policy and Regulation in Energy Transitions

Prior Energy transitions in Sub-Saharan Africa are constrained by weak institutional coordination, fragmented policies, and limited engagement with informal energy practices (Dagnachew et al., 2020; Kovacic et al., 2021; Sedano et al., 2022). Despite policy emphasis on electrification and renewable energy, implementation often overlooks the lived realities of rural populations (Newell and Bulkeley, 2017). Zambia exemplifies this disjuncture: although endowed with renewable resources, only 25% of the population has access to electricity and clean cooking (Lyambai, 2017). Rural communities rely predominantly on traditional biomass, perpetuating deforestation and respiratory illnesses (Kaoma and Gheewala, 2020). While projects like USAID's A2C and ZIFLP promote alternatives, adoption is hampered by high costs, weak enforcement, and poor public awareness (Serenje et al., 2022; USAID A2C, 2021).

Even promising solar initiatives remain underutilised due to undeveloped markets and inadequate community engagement (Mfune and Boon, 2008; Obeng-Darko, 2023). Although existing literature highlights barriers to energy access, few studies offer integrated policy recommendations addressing both charcoal governance and solar PV adoption in rural Zambia. This study addresses that gap by linking policy design to sustainability, enforcement, and inclusive stakeholder engagement. This section consolidates prior findings by highlighting the urgent need for cross sectoral policy coherence, particularly where charcoal regulation and solar market stimulation intersect across rural Sub-Saharan contexts.

5.2.7 Charcoal's Medicinal Properties Overview

Previous research has established charcoal's dual role as both an urban fuel and a medicinal agent, with historical records tracing its therapeutic applications to the Middle Stone Age (Chikumbirike and Bamford, 2021; Herlihy et al., 2013). Its adsorptive properties facilitate detoxification, treating poisonings, lowering cholesterol, and reducing intestinal gas (Lee et al., 2019; Zaini and Mohamad, 2015). In rural Zambia, it is traditionally applied to newborns' umbilical cords for drying and infection prevention (Herlihy et al., 2013; Kar, 2018). However, scholars argue that such practices may not align with modern medical guidelines, necessitating culturally sensitive health education (Hassen and Abdulkadir, 2022). This above writeup further illustrates charcoal's complex role in rural life, medical, economic, and energetic, highlighting the necessity of policies that account for both modern health standards and traditional practices.

5.3 Theoretical Framework

This study applies the Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM) (Chanda et al., 2025a, 2025b) to assess the interplay between charcoal trade, solar photovoltaic (PV) adoption, and sustainability in rural Zambia (see Fig. 3). The framework offers a multi-theoretical lens to understand the complex socio-economic and environmental factors shaping rural energy transitions. Given the urgency of addressing deforestation, energy poverty, and policy gaps in Sub-Saharan Africa, RUDSHAM integrates multiple adoption theories to evaluate both individual decision-making and broader structural influences. At its core, RUDSHAM synthesises three established theories: the Technology Acceptance Model (TAM), Diffusion of Innovations Theory (DOI), and the Theory of Planned Behaviour (TPB). TAM (Davis, 1989; Venkatesh and Davis, 2000) explains technology adoption through perceived usefulness, effort expectancy, social influence, and facilitating conditions. It is particularly relevant in rural Zambia, where solar PV systems are often viewed through a cost-benefit lens that prioritises immediate economic returns over long-term sustainability. DOI (Rogers, 2003a) contextualises how renewable energy solutions spread within communities, emphasizing the role of early adopters, social networks, and innovation diffusion dynamics. Meanwhile, TPB (Ajzen, 1991) accounts for behavioural intentions, linking attitudes, subjective norms, and perceived behavioural control to the slow yet essential transition away from traditional biomass fuels. Beyond these individual-level adoption drivers, RUDSHAM incorporates Social Learning Theory (SLT) (Bandura, 1977) to capture the broader social and cultural dimensions influencing solar PV adoption. Rural communities in Zambia operate within strong social networks, where knowledge-sharing, imitation, and peer influence shape energy choices. Households adopting basic solar PV systems for lighting and phone charging serve as reference points for others, yet the inability to afford higher-capacity systems for irrigation and income-generating activities limits the full transition to productive renewable energy use. In addition to behavioural and social dimensions, RUDSHAM integrates key policy, economic, and environmental variables, making it uniquely suited for analysing energy policy implications.

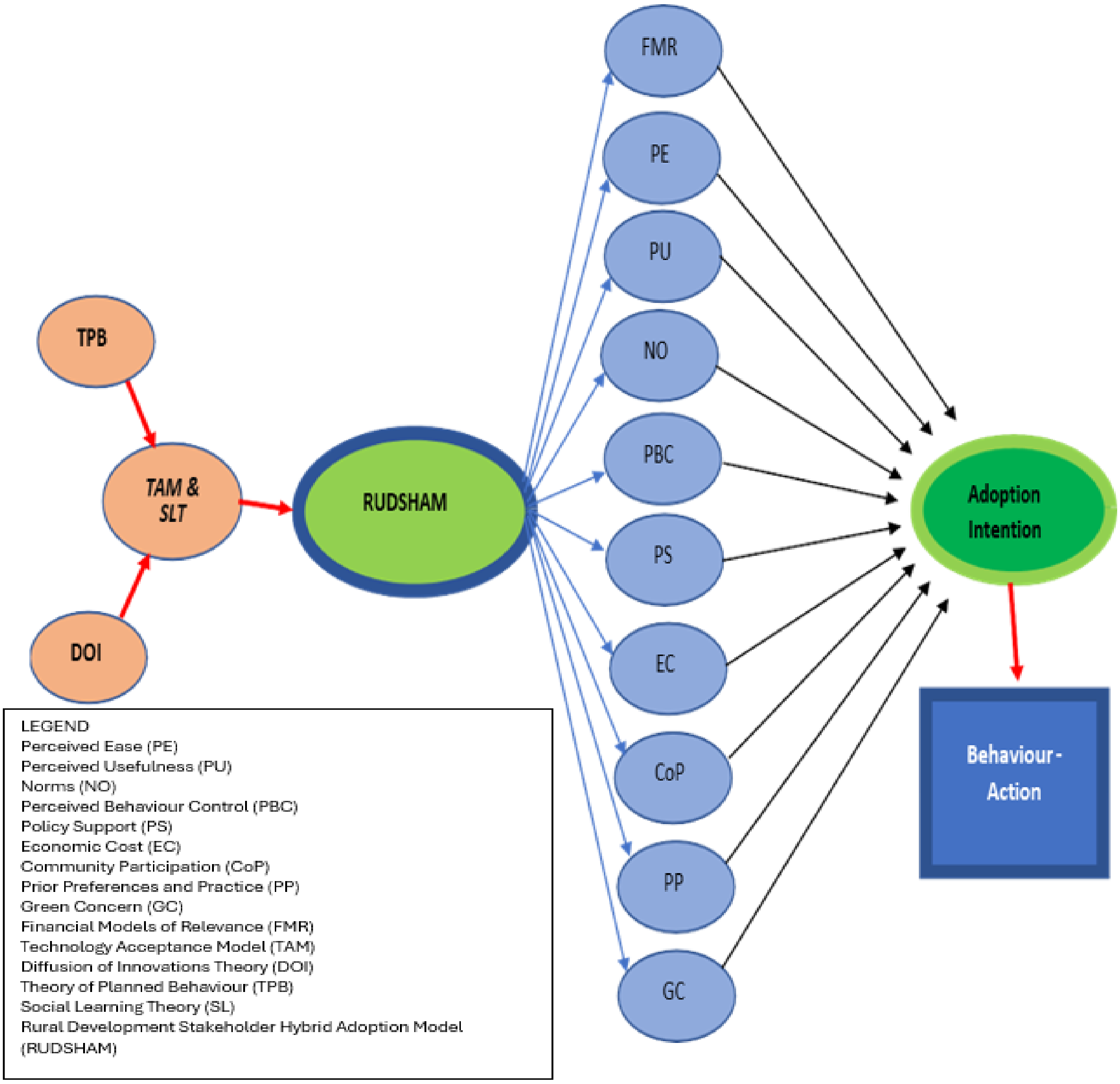

Figure 3: RUDSHAM Hybrid Adoption Model

The study employed a structured deductive approach in applying the RUDSHAM framework. Qualitative data from interviews and focus group discussions were systematically coded in NVivo 14 across the ten RUDSHAM domains. Responses were categorised based on relevance. e.g., user experiences with system maintenance were coded under Perceived Ease (PE), while affordability concerns were linked to Economic Cost (EC). An inductive layer allowed emergent sub themes to be integrated within the existing framework. Coding matrices enabled the identification of patterns across respondent categories. This dual-layered analysis ensured both conceptual fidelity and analytical flexibility. By explicitly mapping empirical data to each RUDSHAM component, the study enhances methodological clarity and allows for replicability in similar energy transition research contexts.

By applying RUDSHAM to the Zambian energy landscape, this study provides an integrated framework for understanding rural energy transitions, balancing technological, cultural, socio-economic, and policy perspectives. The framework's multi-dimensional approach aligns with the energy policy discourse, offering evidence-based insights for designing more effective interventions. This study utilises a mixed-methods approach, incorporating in-depth interviews, focus group discussions, and observational data to rigorously analyse energy adoption behaviours. In doing so, this research contributes to a more nuanced understanding of rural energy transitions, equipping policymakers with actionable strategies to facilitate a just, sustainable, and economically viable energy transition in the Zambian and Sub-Saharan Africa contexts. For a detailed breakdown of RUDSHAM's attributes and applications (refer to Appendices A and B).

5.4 Research Methodology

5.4.1 Research Strategy and Data Collection

This study was conducted over a 28 month period (October 2022 - February 2025) across four rural districts in Zambia: Mkushi Rural (Central Province), Kapiri Rural (Central Province), Chongwe Rural (Lusaka Province), and Luano (Copperbelt Province) (see Fig. 4). These regions were purposively and strategically selected based on:

- Geographical location and high rates of off-grid solar PV penetration.
- Informal energy market prevalence, particularly in solar and charcoal trade.
- Absence of formal e-waste management infrastructure.
- Socio-economic vulnerabilities and low literacy levels.
- Cultural and ecological diversity relevant to wild food harvesting and sustainable livelihoods.
- Mkushi was further selected for its high concentration of White commercial farmers, enabling investigation of their role in shaping rural solar transitions.

A multi-stage sampling approach was employed. In the first stage, the four regions were purposively selected based on geographical, infrastructural, and charcoal production characteristics. In the second stage, participants for focus group discussions (FGDs) and interviews (refer to Appendices C and E) were selected using non-probability sampling techniques. Specifically, convenience sampling was applied for FGDs, which included three FGDs exclusively for full-time charcoal burners, each comprising seven members. Meanwhile, purposive sampling was used to select key informants and stakeholders from the energy and policy sectors. To enhance validity and reliability, a four-week pilot study was conducted with five participants in Luano village (Chingola Rural, Copperbelt Province). This pre-testing phase refined the research instruments, ensuring methodological robustness. Data collection was facilitated by a research assistant fluent in English and multiple local languages (Bemba, Tonga, Soli, Lamba, and Nyanja), alongside the primary investigator, who is proficient in English and has working knowledge of Bemba, Nyanja, and Lamba. Ethics approval for this data collection was granted by the Ethics Committee at the University of Reading (see Appendix J).

The primary data collection methods included in-depth interviews and focus group discussions. A total of 21 full time charcoal burners, 40 rural farmers, 16 commercial farmers, and 3 key stakeholders from solar energy companies and government policymaking institutions were interviewed, with interview durations ranging from 30 to 60 minutes. Ten FGDs were conducted across the four selected areas: three in Kapiri, three in Mkushi, one in Luano, and three in Chongwe. Each FGD consisted of 7 to 12 participants, ensuring diverse perspectives. Of the ten total FGDs, three were exclusively dedicated to full time charcoal burners in Mkushi, Luano, and Chongwe, with seven members per group. Gender-sensitive research practices were incorporated by organizing both mixed gender and separate FGDs for men and women, facilitated by village headmen or councillors to encourage trust and mitigate dominance bias. Participants received refreshments and tokens of appreciation for their time and insights. Topics discussed in these interviews included economic dependence on charcoal, perceived demand and impacts of the charcoal trade, profitability of charcoal, solar PV adoption and its barriers, charcoal use and its gender, socio-economic, and cultural dynamics, as well as policy approaches to charcoal regulation.

To ensure data security and ethical compliance, all recorded interviews, photographs, and video clips, captured with full informed consent, were securely stored on Reading University's OneDrive cloud account with restricted access. Data analysis was conducted using NVIVO 14, ensuring methodological rigour and systematic thematic analysis guided by the RUDSHAM framework (Chanda et al., 2025a, 2025b). Interview transcripts and FGD recordings were coded into themes, employing colour-coding techniques and NVIVO's advanced analytical tools to identify patterns, relationships, and insights. NVIVO facilitated the organization of data linked to key RUDSHAM attributes, including Perceived Usefulness (PU), Policy Support (PS), and Community Participation (CoP). This thematic analysis approach enhanced the credibility, reliability, and depth of the study's findings.

Figure 4: Map of Zambia (UN 2022)

5.4.2 Methodology for Carbon Stock Loss

Building on the socio-economic and policy oriented fieldwork outlined in the previous section, this section introduces the ecological dimension of the study by quantifying carbon stock loss associated with charcoal and fuelwood production. Integrating this assessment is critical to situating rural energy transitions within the broader RUDHSAM framework, as it links community energy practices (Perceived Usefulness, Community Participation) with their environmental consequences and policy relevance (Policy Support). By examining both human dynamics and ecological impacts, the methodology provides a holistic foundation for analysing the sustainability of charcoal dependence and the potential of solar PV adoption in rural Zambia.

This study assessed the loss of carbon stocks and future carbon sequestration potential resulting from forest degradation attributable to charcoal and fuelwood production in Zambia and the four selected districts (Chingola - Luano, Kapiri Mposhi, Mkushi, and Chongwe) during the periods 2008 - 2015 and 2016 - 2023. These two consecutive 8 year periods were selected to enable a temporal comparison of forest loss trends over time. The study assumed that all forest loss occurred in natural forests, leading to immediate carbon emissions without considering subsequent land-use changes. Additionally, carbon storage in harvested wood products was not considered, and all harvested biomass was assumed to be immediately emitted. Forest loss data was obtained from Hansen et al.'s dataset (Hansen et al., 2013), using the 2000 tree cover dataset along with the loss year dataset for 2001-2023, which were processed in Quantum Geographic Information System (QGIS 3.34) The dataset has a 30 metre (900m^2/pixel) spatial resolution, which enables precise measurement of forest loss in the four regions. A 10% canopy threshold was applied to classify forest cover, aligning with standard global forest definitions (FAO-FRA, 2025). To estimate forest loss area (ha), the 2000 tree cover percentage was combined with the binary loss year dataset, so that the calculation accounts for the proportional canopy cover lost in each affected pixel, rather than assuming a uniform loss across all pixels classified as forest loss.

Charcoal and fuelwood production is estimated to account for approximately 90% of forest loss in Zambia (Forest Trends, 2021; LCMS, 2022; USAID A2C, 2021; ZNCAF, 2023), and this proportion was applied to both national and district-level loss data for the carbon stock calculations. Carbon stock loss was calculated based on the carbon stock of aboveground biomass (AGB), as belowground biomass is typically not removed or combusted in charcoal production processes. The values for AGB (69.6 t/ha) and Carbon Fraction (0.47) were derived from the IPCC 2006 Guidelines and 2019 Refinement (IPCC, 2019, 2006). The AGB value was based on the Tropical Dry Forest (≥20 years) category in IPCC guidelines, while the carbon fraction was applied as the default IPCC value. An emission factor of 1.00 was applied, assuming all harvested biomass is immediately combusted and released to the atmosphere. The following equations were used for calculation (refer to equations (1) – (4)):

Carbon Stock Loss (tC) = Forest Loss (ha)×AGB×Emission Factor×Carbon Fraction
(Equation 1)

Carbon Stock Loss (tCO_2) = Carbon Stock Loss (tC)×3.67
(Equation 2)

Additionally, the annual carbon sequestration potential that would have occurred if the forests had remained intact was estimated. This estimation was based on the AGB Growth Rate for Tropical Dry Forests (1.6 t/ha/yr) from IPCC (2019). The future sequestration potential was determined using the equations:

Future Carbon Sequestration Calculation (tC/yr) = Forest Loss (ha)×AGB Growth Rate (t/ha/yr) ×Carbon Fraction
(Equation 3)

Future Carbon Sequestration (tCO_2 /yr)= Future Carbon Sequestration (tC/yr)×3.67
(Equation 4)

This methodological approach enables a comprehensive assessment of forest loss-related carbon emissions and the foregone sequestration potential, contributing to the broader discourse on climate change mitigation and energy transitions in Sub-Saharan Africa.

5.5 Findings

This section synthesises empirical data gathered from charcoal producers, commercial farmers, and rural residents in four rural areas in four districts. Findings are organised around thematic domains grounded in the RUDSHAM framework, illuminating the dynamic interplay between energy practices, economic realities, environmental degradation, and policy responses. The evidence presented draws from in-depth interviews and focus group discussions.

5.5.1 Economic Dependence on Charcoal Trade

These findings are grounded in the discussion of economic marginalisation, informal livelihood strategies, and solar uptake trade-offs as observed during the fieldwork. The results in Table 1 indicate that charcoal burning persists in the studied communities due to economic hardship, seasonal farm incomes, and unemployment. Social networks sustain the trade, while charcoal income paradoxically enables limited solar PV adoption and agricultural investments, despite its environmental consequences and the continued demand-driven deforestation. These findings intersect with the Economic Cost (EC) and Perceived Usefulness (PU) domains of RUDSHAM, suggesting that while charcoal offers short-term income, its role in enabling solar PV uptake remains contextually limited. These insights underline how economic imperatives simultaneously reinforce environmentally detrimental behaviours and enable limited transitions to clean energy, highlighting a tension central to rural energy transitions in Zambia.

Table 1 :Economic and Livelihood Dependence on Charcoal Trade

Participant	Direct Quotation	Source
(a)	*"Life has become very expensive. There are no jobs, and farming inputs are costly, leading to poor harvests and less disposable income. Hence, we are left with no option but to look for extra income sources through charcoal burning."*	Charcoal Burner FGD 1
(b)	*"Farm jobs are seasonal in nature, just like income from agriculture. Hence, we use other means to bridge the financial gap through the use of charcoal, which is always in high demand."*	Charcoal Burner FGD 1
(c)	*"The charcoal business is not abnormally high in profit, and I know the negative consequences of charcoal burning, but I have no option. It's better to engage in charcoal burning than to steal or go around begging for food from people."*	Charcoal Burner Interview 21
(d)	*"It's not by choice that I entered the charcoal business. I have literally tried everything, and it has not worked. The only thing that has worked for me is charcoal burning. To me, it's a source of livelihoods, a matter of life and death."*	Charcoal Burner Interview 6
(e)	*"The relatively easy money and constantly increasing demand have pulled many into the charcoal business, in addition to those who were pushed into the charcoal business out of poverty and unemployment."*	Charcoal Burner Interview 9
(f)	*"The income from charcoal burning has helped us in buying solar home systems and paying back the SHS loans, including chargers, torches, and solar home systems. The income also supplements buying fertiliser to help with agriculture."*	Charcoal Burner FGD 2
(g)	*"Some of us never really planned to be charcoal burners, but we were introduced to it and got addicted after we cleared a farm, produced the charcoal, and sold. The money was sweet! laughs!"*	Charcoal Burner FGD 2
(h)	*"The knowledge about charcoal burning was handed down to me by my parents, and through observation and early exposure to it, I learned and started my own business. Now, I am proudly self-employed and even*	Charcoal Burner Interview 14

	hire some people to help on some big projects. I am a boss...laughs…charcoal burner boss…laughs."	
(i)	*"I got attracted to charcoal burning because I was exposed to it through my relatives and forefathers, who were also in the trade. It's a family business."*	Charcoal Burner Interview 6
(j)	*"I have managed to buy a TV and have lighting in my house through income from charcoal burning."*	Charcoal Burner Interview 7
(k)	*"I am very grateful to God for the charcoal business, which has really been helpful to me. The farm that you see, including the bicycle that I am riding, are all products of income from charcoal burning."*	Charcoal Burner Interview 1
(l)	*"To ask a rural person who depends on charcoal burning to stop, you are basically asking him to give up his income, and it's a challenge just as many of us would resist if we were told to stop doing what brings us income, such as farming or our jobs. Alternatives will need to be found, but as long as there is demand for charcoal, no matter what laws are put in place, the problem of charcoal burning is likely to continue for a long time until all the trees run out."*	Commercial Farmer Interview 5

5.5.2 Deforestation and Charcoal Trade Findings

This theme emerged from interviewees' observations on biodiversity loss, land-use pressures, and declining forest quality, corroborated by ecological field assessments. Empirical evidence in Table 2 highlights that shrinking forests force charcoal producers to cut smaller and fruit trees, threatening biodiversity and food security. While charcoal burning accelerates deforestation, agriculture and timber harvesting also contribute. Weak environmental awareness and poor policy enforcement further endanger Zambia's remaining forests. This finding engages with Green Concern (GC) and Policy Support (PS), revealing limited environmental awareness and enforcement. However, the extent of charcoal's contribution to deforestation must be interpreted alongside other land-use drivers. These findings reflect the complexity of attributing forest loss to a single activity and reinforce the importance of multifaceted, cross-sectoral responses to ecological degradation.

Table 2: Deforestation and Charcoal Trade Findings

Participant	Direct Quotations	Source
(a)	*"In the past, only mature, good trees that produced the best charcoal were used for charcoal production. But with the shrinkage of forests, we are now forced to use even small trees and sometimes fruit trees."*	Charcoal Burner FGD 2
(b)	*"Times are hard, and there is so much demand for charcoal with fewer right trees. Hence, we have been forced to start cutting even fruit trees and trees with medicinal qualities."*	Charcoal Burner FGD 1
(c)	*"Some of us are involved in both mopane worm collection and charcoal burning. The bad thing I have noticed is that some of the best trees used for charcoal burning are also host trees for mopane worms, such as Mpasa [Julbernardia globiflora], Mutondo [Cordyla Africana], and Miombo [Brachystegia boehmii]. Their loss has a double impact, affecting both charcoal burning and the mopane worm trade, which borders on food security in rural areas."*	Charcoal Burner FGD 1
(d)	*"I own some planes, and I have been flying between Lusaka and Mkushi, and gosh, when you look at how the number of trees has reduced since 1986 to now. It's a sad state of affairs. I mean, it used to be green all over, and now it's just patches everywhere."*	Commercial Farmer Interview 9
(e)	*"The trees that we mostly use for charcoal burning include Umutondo [Cordyla Africana], Umubanga [Pericopsis angolensis], Mpasa [Julbernardia globiflora], Kaputu [Brachystegia spiciformis], Umuombo [Brachystegia stipulate], Umusamba [Brachystegia longifolia], Imitobo [Anisophyllea boehmii], and Umulombwa [Pterocarpus angolensis]."*	Charcoal Burner FGD 2

(f)	*"The people blame us for the lack of rain, but we are not the only ones cutting down trees. Those doing farming are sometimes even worse. And a lot of people cut trees for timber and other purposes, so they cannot heap the entire blame on us. It's not fair."*	Charcoal Burner FGD 1
(g)	*"When you look at the villages and the areas where rural people live, all the trees are gone compared to the area on the side of the commercial farmers, which is well preserved. It's so sad."*	Commercial Farmer Interview 2
(h)	*"We have planted about 3 hectares of gum trees and eucalyptus, which we allow our workers to use for firewood. In addition, we give our workers trees that fall naturally, but deliberate cutting of trees is strictly prohibited and punishable through disciplinary action."*	Commercial Farmer Interview 11
(i)	*"There are trees that can be planted and harvested for making charcoal. The government needs to take this seriously."*	Commercial Farmer Interview 5
(j)	*"Both charcoal and agriculture contribute to deforestation, but charcoal is worse."*	Commercial Farmer Interview 5
(k)	*"Environmental understanding in Zambia is low despite the country being among the top five or ten countries with the highest deforestation. At this rate, there will be no forests left by the time the population hits 100 million."*	Commercial Farmer Interview 9

5.5.3 Charcoal Profitability and Seasonality

This segment draws from seasonal patterns in price and labour allocation that emerged during interviews and correlates with the Economic Cost (EC) and Prior Preferences (PP) constructs. The results in Table 3 show that charcoal profitability fluctuates seasonally, peaking during cold months and the rainy season due to increased demand and limited supply. However, rural producers earn minimal profits compared to urban retailers, exacerbating income disparity and reinforcing dependency on charcoal burning as a livelihood. Linking to Prior Preferences and Practice (PP) and Economic Cost (EC), seasonal profitability appears to reinforce dependence, though this dynamic could shift under alternative livelihood options and market restructuring. Thus, charcoal's seasonal profitability masks its structural inefficiency for rural livelihoods and reveals a cycle of subsistence exacerbated by unequal value chain participation.

Table 3: Charcoal Profitability and Seasonality

Participant	Direct Quotation	Source
(a)	*"Profitable months for charcoal, even if it is available throughout the year, are June to July when it's cold. Hence, more people need warmth and use charcoal for heating, bathing water, and poultry farming to warm the chickens."*	Charcoal Burner Interview 3
(b)	*"Around harvest time, there is more disposable income as people sell some of the farming produce from the previous year."*	Charcoal Burner FGD 2
(c)	*"The other profitable months are during the rainy season because not everyone is willing to do charcoal burning during this period, as it is more difficult. The kiln could be soaked, or the charcoal harvest process can be compromised when the charcoal is buried under sand and exposed to rain."*	Charcoal Burner FGD 2
(d)	*"In the dry season and at the beginning of the rainy season, people are busy with farming, preparing for food for the next year, and also trying to plant cash crops that are profitable. During the rainy season, there are more jobs available on different farms where people can do some piecework and raise some income instead of engaging in charcoal burning."*	Charcoal Burner FGD 1
(e)	*"The profit from charcoal mainly goes to the retailers who sell in town and along the road. The profit for a 25m³ kiln on average is around K800 US ($32) for the producer whilst the retailer gets net profit of around K2,000 ($80 US)."*	Charcoal Burner Interview 5
(f)	*"We make very little profit; that's why we have stayed in this business and have failed to diversify. Tubombelafye ubuchushi (we are only in this because of poverty and have no other alternative). It's so painful to be taken advantage of, but there is nothing much we can do. We are not united, so we are taken advantage of as we set charcoal prices individually and many times at giveaway prices."*	Charcoal Burner FGD 1
(g)	*"The only way to make more money is to make more charcoal. Hence, sometimes we combine forces to make big kilns so that we get more charcoal and increase our profits."*	Charcoal Burner FGD 1

5.5.4 Solar Adoption and Livelihood Diversification

This subsection draws on thematic evidence relating to technology uptake, aspirations, and access to productive-use solar tools facilitated by NGOs. Empirical evidence in Table 4 highlights a growing shift toward solar energy adoption, driven by safety concerns and aspirations for modern living. Access to solar irrigation enables small-scale farmers to transition from charcoal burning to profitable gardening, facilitated by NGO-supported credit schemes for solar-powered water pumps. Findings map onto Perceived Usefulness (PU) and Community Participation (CoP), as solar technology uptake appears aspirational. However, adoption remains uneven and may reflect early-stage transitions rather than a widespread behavioural shift. These observations suggest that solar PV holds transformative potential, yet its scaling remains constrained by economic access, initial capital, and uneven institutional support.

Table 4: Solar Adoption and Livelihood Diversification

Participant	Direct Quotation	Source
(a)	*"The world is changing, and everyone is turning to solar lighting and abandoning candles and traditional lamps. So, we have also joined the bandwagon, as we don't want to be left behind. The house looks better when lit with solar bulbs kwati nikumayadi (like in urban high-cost areas), and you don't have to worry about fires compared to using lamps and candles, which have caused many fires. Some people have actually been killed, or houses have been completely burned down."*	Charcoal Burner FGD 1
(b)	*"Our friends who have solar-powered water pumps can engage in gardening and raise a lot of money even in the dry season. They don't engage in charcoal burning because it's much easier to have a garden than to burn charcoal."*	Charcoal Burner FGD 2
(c)	*"Our NGO provides support with solar irrigation systems for small-scale farmers (SSFs) on a credit basis through providing funds for boreholes and a solar irrigation system that can irrigate up to a lima (50m²). They start with small loans and, over the years, graduate to bigger loans of K20,000 ($800 US), which include solar irrigation systems that they pay back over a period of about four years. One farmer actually made a profit of K20,000 in one farming season from gardening alone."*	Commercial Farmer Interview 8

5.5.5 Economic Barriers and Charcoal Dependency

Grounded in household level financial data and affordability metrics, this section engages with structural economic limitations on renewable energy adoption. The findings in Table 5 reveal that high solar PV costs limit productive use, sustaining charcoal dependence. Land clearing drives opportunistic charcoal burning, while costly fertilisers encourage unsustainable farming. Charcoal income funds solar home solar PV systems, underscoring economic trade-offs in rural energy transitions. This aligns with Financial Models of Relevance (FMR) and Economic Cost (EC). While charcoal income supports solar investment, such trade-offs raise concerns about the scalability and equity of clean energy transitions. The persistence of charcoal reliance reflects not just market failures but systemic affordability challenges that constrain energy diversification.

Table 5: Economic Barriers and Charcoal Dependency

Participant	Direct Quotation	Source

(a)	*"The problem is that people just talk, and there is very little action. If someone could provide us with a credit pay-slow system or affordable loans for solar irrigation systems, all of us would want to get that system. But the problem is that, apart from lighting systems, which are affordable, solar systems for productive purposes have proved to be very expensive and almost outside of our ability to pay. You need to burn the whole forest to afford such a system….laughs!"*	Charcoal Burner FGD 1
(b)	*"The beginning of the farming season sees a lot of opportunistic charcoal burners who join because they must cut trees to prepare agricultural land for farming. New farming areas offer more fertility. But this supply is not enough to satisfy the demand for charcoal when other players are involved, like those whose main business is charcoal burning."*	Charcoal Burner FGD 2
(c)	*"Fertiliser is expensive, and the government subsidies that we used to get for fertiliser have been drastically reduced, to impress the whites so that we can be allowed to borrow money from the West… laughs!"*	Charcoal Burner Interview 7
(d)	*"Fertiliser has destroyed the soil to such an extent that it's almost impossible to get yield without fertiliser and treated seeds. So, we are forced to look for means to raise money to buy these inputs so that we can afford these."*	Charcoal Burner Interview 19
(e)	*"Apart from heating up our homes and helping us cook, charcoal also provides 'lighting' for us by providing income, which we use to make payments for the solar home systems provided by companies like Ready Pay, My Sol, Fenix, and Sun King."*	Charcoal Burner FGD 2
(f)	*"The available solar home system prices and loans depend on the size that you want and can afford, ranging from two-bulb solar home systems costing around K1,300 ($52 US) cash and K1,700 ($68 US) in instalments payable in 18 months. Also, those with four bulbs cost around K3,600 ($144 US) cash."*	Charcoal Burner Interview 17

5.5.6 Safety Risks from Charcoal Burning

Building on the earlier discussion of economic and ecological drivers, this segment turns attention to the environmental hazards and health implications tied to charcoal production practices. The findings in Table 6 highlight the environmental and health risks of charcoal production, including forest fires, respiratory illnesses, and snakebites. Competition for dwindling trees fuels land disputes, while some men misuse earnings, exacerbating social issues. Women, however, invest more responsibly in household needs. Findings relate to Green Concern (GC) and Perceived Behaviour Control (PBC). While health and environmental harms are evident, the uneven awareness and behavioural agency limit systemic change without stronger interventions. Understanding these risks contributes vital insights into the human cost of energy poverty and underscores the necessity of designing energy transition pathways that safeguard health and safety in marginalised settings.

Table 6: Safety Risks from Charcoal Burning

Participant	Direct Quotation	Source
(a)	*"Ifibili (kilns) during the initial lighting process, if not done properly, especially by novices, have led to forest fires. That is a danger, and we ensure that we try to be as careful as possible during the process. But I guess in life, you can't be too careful, especially since the charcoal business is not regulated…it's a free-for-all business."*	Charcoal Burner Interview 4
(b)	*"Times are hard, and there is so much demand for charcoal with fewer right trees. Hence, we have been forced to start cutting even fruit trees and trees with medicinal qualities."*	Charcoal Burner FGD 1
(c)	*"The nearby trees close to the villages and roads have been depleted. Hence, for someone to find good trees, they have to travel long distances, which adds to transport costs. There is serious competition for the few remaining trees, even those on private lands."*	Charcoal Burner FGD 2
(d)	*"Someone tried to cut trees for charcoal burning in an area that was mine, so we got into a serious argument, which the chief had to sort out. It's not the first time this is happening, especially since trees have become rare. People are claiming land that is not theirs… It's survival of the fittest, and you have to be tough…laughs."*	Charcoal Burner Interview 10
(e)	*"We face a lot of dangers and encounter poisonous snakes, especially when we venture into the deep forests far from the villages."*	Charcoal Burner Interview 13
(f)	*"There are several people that have been bitten by poisonous snakes, and some have even died in the recent past."*	Charcoal Burner FGD 2
(g)	*"I sometimes get chest pains that last for weeks from burning charcoal. The smoke and heat do me harm. I take some munkoyo [Rhynchosia venulose] shrub drink to help, or milk if available."*	Charcoal Burner Interview 14
(h)	*"We suffer several negative health effects in the charcoal burning process, including chest pains, headaches, colds, coughs, and TB. But we have no option; otherwise, we die of hunger, what's better?... laughs."*	Charcoal Burner FGD 1
(i)	*"We play down the dangers, but the truth of the matter is that we have seen some of the people who have been involved in charcoal burning for a long-time suffering from chronic coughs like TB."*	Charcoal Burner FGD 1
(j)	*"Women usually use the proceeds from charcoal burning properly, but some men and youths indulge in dangerous behaviour, which exposes them to life-threatening diseases."*	Charcoal Burner Interview 21
(k)	*"Some charcoal burners become excited with the money that they make and end up drinking too much or womanizing, eventually contracting STIs, which not only endanger them but also their spouses. But mostly, women charcoal burners use their money more responsibly to buy household items, pay for SHS, or help educate their children."*	Charcoal Burner FGD 2

5.5.7 Gender Challenges in Charcoal Trade

Following the previous analysis of health and safety concerns, this examination highlights the distinct gender-based constraints and vulnerabilities faced by women in the charcoal value chain. The results in Table 7 reveal significant gender disparities in the charcoal trade, where women face exploitation, financial dependency, and societal stigma. Limited physical capacity, lack of maternity support, and male dominance further disadvantage women, often forcing them into exploitative relationships to sustain their businesses. These results touch on Community Participation (CoP) and Norms (NO), highlighting gendered disadvantages. Yet, further inquiry is needed into how agency and institutional support shape women's pathways within the trade. Incorporating gender-responsive strategies is critical to achieving equitable energy transitions and fostering inclusive rural development across Sub-Saharan Africa.

Table 7: Gender Challenges in Charcoal Trade

Participant	Direct Quotation	Source
(a)	*"As a woman, being in the charcoal business is not very easy because you must hire men to do everything for you, and at the end of the day, your profits are reduced. Some naughty men with bad manners even demand your body as a woman in exchange for free help. Sadly, some women who love money end up giving in… the love of money…laughs."*	Charcoal Burner FGD 2
(b)	*"Women usually use the proceeds from charcoal burning properly, but some men and youths indulge in dangerous behaviour, which exposes them to life-threatening diseases."*	Charcoal Burner Interview 3
(c)	*"It's an uphill struggle to be a woman and a charcoal burner because, traditionally, it's a male-dominated trade."*	Charcoal Burner Interview 10
(d)	*"Many people discourage us and tell us that charcoal burning is for men. As women in the village, we are regarded as second-class citizens without rights… only good for having babies and looking after children…laughs."*	Charcoal Burner Interview 18
(e)	*"It's naturally more difficult for a woman to be a charcoal burner, especially when she is pregnant or breastfeeding, because there is no maternity leave. It means either the business has to stop until she gets back on her feet or she has to comprise childcare leading to health problems in children. In the process of delegating tasks, many women have experienced losses or even gone under."*	Charcoal Burner FGD 1
(f)	*"Some single women involved in charcoal burning are sometimes forced to find a 'special' male partner… laughs… to help out in the business. But not everyone resorts to such desperate measures to stay in business."*	Charcoal Burner FGD 1

5.5.8 Policy and Legal Trade Issues

Expanding from the gender dimension, this section interrogates the disconnect between formal charcoal regulation and the lived realities of enforcement and compliance. Empirical evidence in Table 8 highlights widespread non-compliance due to high permit costs, corruption, and weak enforcement. Bribery sustains the illegal charcoal trade, while officials exploit confiscations. Policies exist but lack enforcement, and without viable alternatives, charcoal production remains essential for livelihoods, exacerbating deforestation and environmental degradation. Findings speak to Policy Support (PS) and Perceived Behaviour Control (PBC). Though policies exist, limited compliance and enforcement show that legal frameworks alone are insufficient without community responsive governance structures. This analysis reveals that charcoal governance reform must be reinforced by local participatory mechanisms and socioeconomic incentives if regulatory strategies are to succeed.

Table 8: Policy and Legal Trade Issues

Participant	Direct Quotations	Source
(a)	*"It's expensive to get permits/licences for charcoal burning. I have never obtained a licence, so I ensure I keep something aside to bribe the forest officers or the police. The police are easier to deal with, but the forest rangers sometimes confiscate the bags, and you lose out."*	Charcoal Burner Interview 4
(b)	*"We are all aware that we need permits to make charcoal, but honestly, no one follows it. I mean, I have never seen anyone within my village and beyond who has gone to get a permit to make charcoal. I mean, we all understand no one planted these trees, so why should someone come up with restrictions on how to make use of God-given resources?"*	Charcoal Burner Interview 6
(c)	*"I feel for the forest officers because they have bad manners and bad hearts and like confiscating hard-earned charcoal. They can be a nightmare because the cost of retrieving the charcoal once confiscated is as high as K500 ($20 US) to K700 ($28 US), which is almost equivalent to the entire profit, you see."*	Charcoal Burner Interview 5
(d)	*"Sometimes we suspect that these officers just set deliberate ambushes to confiscate our charcoal on purpose so that they can, in turn, go and sell the charcoal. Open their own small shops over our sweat… very evil people."*	Charcoal Burner FGD 1
(e)	*"Once confiscated, we rarely pay the penalty because usually, it is even higher than the value of the charcoal. So, the best thing is to negotiate with the arresting officer so that you give him something before it goes to the offices, and you can go and sell the charcoal and make some money... laughs... you have to be sharp."*	Charcoal Burner FGD 2
(f)	*"Look, I don't understand how they calculate these permit issues for charcoal burning. Once I was clearing my farm and, as a law-abiding citizen and a Christian, I went to the council to inquire how much I would have to pay to get a licence for making charcoal. The quotation amount that I was given was so huge that I ended up just burning the trees. Maybe it's because I am a 'Muzungu' (White) ."*	Commercial Farmer Interview 6
(g)	*"Policies and laws against charcoal burning are there, but every day you see truckloads of charcoal going into the cities, and you wonder how this is possible. The government is not doing much. The policies are just on paper."*	Commercial Farmer Interview 7
(h)	*"To some extent, the government tries to discourage people from deforestation, but they don't offer any serious alternatives; hence, it fails to implement. With the availability of alternatives, almost all of us are willing to stop and do something better."*	Charcoal Burner FGD 1
(i)	*"They have tried to stop us, but it's just on paper, and it's not real. Whoever would try to ban the production of charcoal would dig his own grave and the graves of many charcoal burners and their families. If it's a political party, no doubt, it would definitely lose elections because the votes come from here."*	Charcoal Burner FGD 2
(j)	*"Some chiefs and headmen are corrupt and are actually at the forefront of charcoal burning since they have huge traditional portions of land by virtue of their positions, which they use to make charcoal and cut trees."*	Charcoal Burner FGD 1

5.5.9 Urban Demand and Market Drivers

Transitioning from governance issues, this focus area examines the market side dynamics that perpetuate charcoal production, particularly the role of urban consumption patterns. The findings in Table 9 indicate that urban demand, worsened by economic hardship and load shedding, sustains charcoal production. Rural communities use firewood, while charcoal is exported to cities. Stagnant prices and rising competition reduce profits, emphasizing the need for urban focused policies to curb deforestation and promote energy alternatives. This reflects Perceived Usefulness (PU) and Financial Models of Relevance (FMR). The results suggest that urban demand sustains rural supply chains, but without price incentives or market shifts, change may be marginal and localised. These findings suggest that interventions aimed at rural producers will fall short unless urban demand side policies, including affordable electricity and clean cooking, are implemented in tandem.

Table 9: Urban Demand and Market Drivers

Participant	Direct Quotations	Source
(a)	*"The introduction of fertiliser and total dependence on it has seen many portions of land quickly lose fertility due to chemical use, meaning that new farms need to be opened."*	Charcoal Burner FGD 1
(b)	*"In the rainy season, it's difficult to do charcoal business, as it sometimes gets compromised due to rain and might be difficult to store for a long time while retaining quality."*	Charcoal Burner Interview 6
(c)	*"Our biggest customers have been in urban areas, especially in peri-urban areas where you find the lower class who do not earn much. But in the last few years, since load-shedding shifted gear, even people from high-cost areas are buying charcoal."*	Charcoal Burner FGD 2
(d)	*"The recent worsening of economic conditions in the country has worked to our advantage. Without load-shedding and increased ZESCO electricity tariffs, we wouldn't have seen this surge in demand for charcoal."*	Charcoal Burner FGD 1
(e)	*"Apart from charcoal, there are very viable income-generating ventures that don't require much capital. If we had alternative sources of income and jobs, we would have long shifted and stopped this charcoal business."*	Charcoal Burner Interview 7
(f)	*"Prices of charcoal have been almost stagnant for a while, whilst the cost of living has been increasing, and the number of charcoal burners has increased due to increased demand."*	Charcoal Burner Interview 16
(g)	*"So many people have joined the charcoal trade, and in the process, the prices have been affected, which has caused them to come down, especially in places where there are many in one place."*	Charcoal Burner FGD 1
(h)	*"Firewood is used in rural areas, and charcoal is exported to urban areas because many people in urban areas cannot afford electricity, especially when it comes to heating and cooking. People in rural areas depend on firewood and do not need charcoal except mainly for export to urban areas to earn an income."*	Commercial Farmer Interview 2
(i)	*"The solution to charcoal burning does not lie in the rural areas; it lies squarely in the urban places."*	Commercial Farmer Interview 2
(j)	*"If charcoal was used just in the rural areas, it would be sustainable, and there wouldn't be all these problems. The issue about charcoal burning is not so much to do with the local community but the commercialization aspect, which has been brought about by the demand from urban areas. I believe the solution regarding charcoal lies in the urban areas."*	Commercial Farmer Interview 7
(k)	*"This charcoal problem is a complex thing and has many facets. As much as the charcoal business drives the rural economy, you see, people in urban areas, where the unemployment rate is actually higher than in the rural areas, due to economic reasons, cannot afford to pay for power. Since there is no firewood, they resort to charcoal, which they can afford."*	Commercial Farmer Interview 5

5.5.10 Charcoal Trade's Political Complexity

The discussion now turns to the embedded political and cultural realities that inhibit reform, drawing from local governance and traditional authority structures. Empirical evidence in Table 10 highlights that charcoal burning persists due to survival needs and weak enforcement. Chiefs attempt sensitisation, but headmen remain passive. Heating for cooking and warmth drives deforestation, necessitating urgent policy interventions to promote alternative energy sources and sustainable income opportunities. Findings connect to Norms (NO) and Policy Support (PS). Though traditional leaders attempt regulation, fragmented authority and grassroots disengagement suggest limited traction for long-term change under current governance dynamics. The findings imply that efforts to shift from biomass must acknowledge charcoal's symbolic functions, ensuring that proposed alternatives resonate with local value systems. This highlights that charcoal is not only an environmental and economic issue but also a politically entangled livelihood practice requiring nuanced and multi-scalar policy responses.

Table 10: Charcoal Trade's Political Complexity

Participant	Direct Quotations	Source
(a)	*"No one stops us because we rub shoulders with even headmen and fight over trees in the bush as we do business in charcoal because they also have to survive."*	Charcoal Burner Interview 3
(b)	*"Some chiefs, to some extent, try to sensitise subjects about the dangers of charcoal burning, but they can only go so far in the absence of alternative sources of income. Headmen, on the other hand, don't do anything much to discourage charcoal burning."*	Charcoal Burner FGD 1
(c)	*"Telling people to stop charcoal burning is like asking them to commit suicide, and I am sure no normal human being would want to do that."*	Commercial Farmer Interview 4
(d)	*"Lighting is good, but heating seems to be the main problem, which must be sorted out soon; otherwise, in a few years, we will have no trees remaining. Truth be told, people can do without lighting because it comes naturally, but heating for cooking and warmth is a necessity."*	Commercial Farmer Interview 5

5.5.11 Charcoal's Cultural and Non-Energy Uses

Extending the inquiry into socio-cultural terrain, this portion illuminates the deeper symbolic, medicinal, and spiritual meanings ascribed to charcoal in rural life. The results in Table 11 show that firewood and charcoal hold deep cultural significance beyond cooking, serving as social focal points and integral elements of traditional rural African life. Additionally, charcoal has medicinal, spiritual, and functional uses, reinforcing its entrenched role in rural communities. These findings relate to Prior Preferences and Practice (PP) and Norms (NO). Charcoal's embedded social and symbolic meanings complicate substitution efforts, warranting culturally sensitive alternatives rather than purely technical interventions. The results imply that efforts to shift from biomass must acknowledge charcoal's symbolic functions, ensuring that proposed alternatives resonate with local value systems.

Table 11: Charcoal's Cultural and Non-Energy Uses

Participant	Direct Quotation	Source
(a)	*"Firewood and charcoal brazier culture is not just about cooking food and eating. It comes with its own social benefits that villages appreciate and have grown up living with. There is a lot that happens around the fire in Africa. More like the bonfire in Europe, which is nice to look at as*	Commercial Farmer Interview 6

	you excitedly interact, except in Africa, it's done on a daily basis and engraved in the culture."	
(b)	*"Community social life revolves around fire in the kitchen. Around the fire, that's where you cook, sit, talk, interact, and get entertained whilst resting and catching up. Without fire, people feel out of place and as if their life is gone, empty and meaningless."*	Commercial Farmer Interview 7
(c)	*"I have built my workers very good houses and even provided some stoves for them, but even with stoves inside, they still bring the charcoal braziers into their homes to sit around them… laughs."*	Commercial Farmer Interview 5
(d)	*"It would be a long time before the culture from 'imbaula' (charcoal brazier) and wood would change because firewood is about culture."*	Commercial Farmer Interview 6
(e)	*"There are places like South Africa where I have lived before, and because there are no forests there, people use cow dung and maize cobs for heating, and they are used to it. This can also work in Zambia except the use of firewood and charcoal is a cultural thing, and it's deeply entrenched in people."*	Commercial Farmer Interview 4
(f)	*"Firewood and charcoal brazier culture is not just about cooking food and eating. It comes with its own social benefits that villages appreciate and have grown up living with. There is a lot that happens around the fire in Africa."*	Commercial Farmer Interview 7
(g)	*"Apart from selling charcoal and using it for heating and cooking, we also use it for various other purposes. In its crushed form, charcoal is used to neutralise snake poison, particularly in emergencies when medical help is far. It is also taken for stomach aches and used as chalk for writing. Additionally, some people use it for painting houses and facial decorations during traditional entertainment. In certain cultural beliefs, a piece of charcoal is placed in a bag of mealie meal to prevent its magical theft."*	*Charcoal Burner FGD 2*
(h)	*"Charcoal is commonly used for treating poison ingestion and stomach aches, as well as for neutralizing snake venom. It is also believed to ward off evil spirits and witches and is sometimes placed under a pillow to prevent bad dreams. Historically, charcoal was buried with individuals who died tragically or were barren, as it was thought to prevent such misfortunes from recurring in future generations, which were perceived as curses."*	*Charcoal Burner FGD 1*
(i)	*"When I was a young boy, charcoal saved my life. I mistakenly drank kerosene, and I was given crushed charcoal mixed with water to drink. Within an hour, I vomited, and the dizziness I had been feeling disappeared soon afterward."*	*Charcoal Burner Interview 3*

5.5.12 Challenges in Energy-Efficient Cooking Adoption

Following cultural perceptions, this part considers the barriers to adopting energy-efficient cooking technologies, especially improved cookstoves and braziers. The findings in Table 12 highlight significant resistance to energy efficient braziers due to their perceived inefficiency in generating adequate heat for traditional cooking methods. Cultural norms, household dynamics, and slow cooking times discourage adoption, though alternatives like maize cob charcoal show promise when they meet user expectations. Linking to Perceived Ease (PE) and Norms (NO), resistance to efficient braziers reflects not only technical shortcomings but also deep-rooted culinary practices and intergenerational household norms that influence acceptability. This suggests that technological innovation alone is insufficient, behavioural, cultural, and contextual factors must be embedded into the design and dissemination of energy-efficient alternatives.

Table 12: Challenges in Energy-Efficient Cooking Adoption

Participant	Direct Quotation	Source

(a)	*"I tried to distribute some free energy-efficient braziers (EEBs) to my farm workers, but the women were the first to complain that it was a bit too high and didn't provide as much heat as firewood or the charcoal brazier. Hence, within a short time, the EEBs were abandoned."*	Commercial Farmer Interview 3
(b)	*"We were given some free charcoal braziers that used small sticks, but it was just the same, and food took too long to cook, especially 'nshima' (maize meal mash), so we went back to firewood and charcoal, which we have grown up with."*	Charcoal Burner FGD 1
(c)	*"Sometimes, it's not that we are stubborn and refuse to adopt some of the stoves given to us by our bosses, NGOs, etc (I mean, sometimes it's dangerous to go into the bush because you might encounter snakes, wild animals, or even criminals, especially for girls). The problem is that these stoves don't do as good a job. For example, we have moved away from candles to solar lighting because it's a better option. Similarly, if a better cooking stove were provided, I'm sure many of us would switch."*	Charcoal Burner FGD 2
(d)	*"These braziers take so long to cook food. Some of us have husbands with huge appetites and short tempers when food takes too long…laughs… so to maintain peace in the home, we ensure we cook using tried and tested methods like firewood and charcoal… laughs."*	Charcoal Burner FGD 1
(e)	*"Certainly, we don't enjoy the smoke from firewood, which is sometimes choking and makes the pots black on the outside. Hence, we wouldn't hesitate to switch to a cleaner system if it provided the same heat at the same rate as charcoal, firewood, or a modern stove…laughs."*	Charcoal Burner FGD 2
(f)	*"Searching for firewood is hard work and not always easy, especially these days when the forest is dwindling. But it has its own advantages, as it allows people to socialise, take walks, and even gives young girls in love an opportunity to meet their loved ones under the pretext of collecting firewood…laughs."*	Charcoal Burner Interview 4
(g)	*"Because of the so-called efficient braziers, I once ended up cooking ubwali ubwabishika (grossly undercooked maize mash due to insufficient heat). It was so embarrassing for my husband and family because I am a well-taught African woman in every aspect. From that day, I swore never to use them again."*	Charcoal Burner Interview 5
(h)	*"Through the North Swaka Project, we are promoting an energy-efficient wood stove, discouraging charcoal burning, teaching efficient agricultural methods that use less space and minimal fertiliser, promoting beekeeping and finding a market for honey. We also teach people how to make charcoal from maize cobs, and this charcoal doesn't smoke and is hot enough to cook 'nshima' (mashed maize meal) properly."*	Commercial Farmer Interview 3

5.5.13 Environmental and Economic Charcoal Impacts

Returning to the environmental domain, this discussion evaluates the ecological degradation and production dynamics within charcoal systems. The results in Table 13 indicate that charcoal production is labour intensive, requiring skill and constant monitoring to ensure quality. Despite high tree consumption, reforestation efforts are minimal, as many believe forests regenerate naturally. Economic constraints also drive continued deforestation due to affordable tree acquisition costs. These findings engage with Green Concern (GC) and Community Participation (CoP). While producers recognise environmental degradation, limited institutional support and economic alternatives undermine collective reforestation or ecosystem restoration efforts. The findings offer empirical weight to arguments that environmental degradation must be addressed not only through enforcement but by transforming the economic rationalities that drive unsustainable resource extraction.

Table 13: Environmental and Economic Charcoal Impacts

Participant	Direct Quotations	Source
(a)	*"The beginning of the farming season sees a lot of opportunistic charcoal burners who join because they must cut trees to prepare agricultural land for farming. New farming areas offer more fertility. But this supply is not enough to satisfy the demand for charcoal when other players are involved, like those whose main business is charcoal burning."*	Charcoal Burner FGD 1
(b)	*"If someone is serious, they can finish a whole kiln in a period of three weeks and start another cycle depending on the size of the kiln. Typically, the kiln sizes are around 5m long, 2m wide, and 2.5m high, giving a total volume of 25m³."*	Charcoal Burner FGD 2
(c)	*"Charcoal burning is very difficult and requires a lot of hard work and skill, failure to which you can produce half-baked or overbaked charcoal. It requires constant monitoring. Sometimes you must camp and sleep by the kiln. It's difficult from the tree-cutting to the burning process, which, if not monitored, sometimes switches off."*	Charcoal Burner FGD 2
(d)	*"To be honest, almost none of us, if not all, have planted any trees except for maybe a few people who have planted fruit trees at their places. This is mainly because we believe that forests can rejuvenate as the trees grow naturally."*	Charcoal Burner FGD 1
(e)	*"For a 25m³ kiln, we use a minimum of about 10 trees ranging from around 7 metres in height and above. For very big trees, it might take just a few to make a kiln, but they tend to be more expensive if you are buying them."*	Charcoal Burner FGD 3
(f)	*"The cost of buying about 10 trees for one kiln of 25m³ is around K500 ($20), and the cost of a single tree averages around K100 ($4), which is used for various purposes, including traditional timber processing."*	Charcoal Burner FGD 3

5.5.14 Carbon Stock Loss Results

Concluding the empirical findings, this segment quantifies the climate impact of charcoal production through carbon stock loss and sequestration potential. The findings from Tables 14 and 15 reveal a sharp increase in carbon stock loss and future carbon sequestration potential due to forest degradation driven predominantly by charcoal and fuelwood extraction across Zambia and its selected rural districts. From 2008 to 2023, Zambia lost over 49 million tonnes of carbon (tC), equivalent to more than 183 million tonnes of CO_2 , with significant emissions concentrated in districts like Mkushi and Kapiri Mposhi. Projections indicate continued loss of future carbon sequestration, with over 2.6 million tonnes of CO_2 lost annually since 2016 in Zambia. This section maps onto Green Concern (GC) and Policy Support (PS), illustrating systemic environmental loss. However, attributing causality solely to charcoal overlooks structural energy poverty and enforcement limitations in land-use policy. The data strengthens the case for urgent climate-smart interventions and place Zambia's charcoal dilemma within the broader discourse on global carbon responsibility and rural energy justice.

Table 14: Carbon Stock Loss

Carbon Stock Loss Due to Charcoal and Fuelwood										
	Zambia		Chingola		Kapiri Mposhi		Mkushi		Chongwe	
	2008~2015	2016~ 2023	2008~ 2015	2016~ 2023	2008~ 2015	2016~ 2023	2008~ 2015	2016~ 2023	2008~ 2015	2016~ 2023
Forest area loss (ha)	620,733	1,074,226	2,502	5,611	18,985	38,765	20,226	40,804	3,377	6,431

% of Forest Loss: Charcoal/Fuelwood	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
Forest Loss: Charcoal/Fuelwood (ha)	558,660	966,803	2,252	5,050	17,087	34,889	18,203	36,724	3,039	5,788
AGB (t/ha)(1*)	69.6	69.6	69.6	69.6	69.6	69.6	69.6	69.6	69.6	69.6
Emission Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Carbon Fraction of Aboveground Biomass (2*)	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Carbon stock loss(tC)	18,274,876	31,626,073	73,661	165,192	558,934	1,141,273	595,470	1,201,302	99,422	189,334
Carbon stock loss(tCO_2)	67,068,795	116,067,687	270,335	606,256	2,051,286	4,188,470	2,185,374	4,408,780	364,877	694,855

1 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*
Table 4.7>Tropical dry forest>Africa>Secondary more than 20 years (IPCC, 2019)

*2*2006 IPCC Guidelines for National Greenhouse Gas Inventories*
TABLE 4.3 >Default value (IPCC, 2006)

Table 15: Future Carbon Sequestration Potential

Future Carbon Sequestration Loss Due to Charcoal and Fuelwood										
	Zambia		**Chingola**		**Kapiri Mposhi**		**Mkushi**		**Chongwe**	
	2008~2015	2016~2023	2008~2015	2016~2023	2008~2015	2016~2023	2008~2015	2016~2023	2008~2015	2016~2023
Forest Loss: Charcoal/Fuelwood	558,660	966,803	2,252	5,050	17,087	34,889	18,203	36,724	3,039	5,788
AGB Growth Rate （t/ha/yr） (1*)	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Carbon Fraction	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Future Carbon Sequestration Loss (tC/yr)	420,112	727,036	1,693	3,797	12,849	26,236	13,688	27,616	2,285	4,352
Future Carbon Sequestration Loss (tCO_2 /yr)	1,541,811	2,668,223	6,215	13,937	47,156	96,287	50,238	101,351	8,388	15,974

*1*2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*
Table 4.9>Tropical>Tropical dry forest>Africa (≥20 y) (IPCC, 2019)

5.6 Discussion Section

This section synthesises the findings of the study in relation to existing literature and policy contexts. The discussion is structured thematically, highlighting the complexities of charcoal dependence, solar PV adoption, and their intersection with rural livelihoods and environmental sustainability.

5.6.1 Economic Dependence and Transition Paradox

Understanding the entrenched economic dependence on charcoal production is essential for contextualising the slow uptake of renewable energy technologies in rural Zambia. The findings of this study seem to highlight the deep-rooted economic dependence on charcoal production in rural Zambia, shaped by poverty, seasonal agricultural income, and limited employment opportunities (see Table 1). Many charcoal producers view the trade as a survival mechanism rather than a choice, with some describing it as their only viable means of livelihood (Charcoal Burner Interview (d); Charcoal Burner FGD 1 (a)). This aligns with broader regional studies that emphasise how charcoal serves as a financial fallback for rural populations facing economic instability (Rose et al., 2022; Steel et al., 2022). The steady urban demand for charcoal seems to further entrench the trade, ensuring its continued profitability despite low returns (Charcoal Burner Interview (e); Nyarko et al., 2021).

The findings indicate that social networks and generational knowledge play a critical role in sustaining the charcoal trade(Chanda et al., 2025a). Several participants reported being introduced to charcoal burning by family members, indicating an inherited practice passed down through generations (Charcoal Burner Interview (h, i)). Studies in SSA confirm that cultural transmission of charcoal-making skills perpetuates its role in rural economies, often limiting exposure to alternative livelihoods (Gumbo et al., 2013; Kutsch et al., 2011). Moreover, the "charcoal trap" persists due to the ease of entry into the business and the absence of accessible, sustainable alternatives (Commercial Farmer Interview (l)). Despite its environmental drawbacks, income from charcoal burning has facilitated access to solar home systems (SHS), televisions, and agricultural investments (Charcoal Burner Interview (j, k); Charcoal Burner FGD 2 (f)). This paradox mirrors findings from (Nygaard et al. (2016) and Tinta et al. (2023), which suggest that unsustainable charcoal-generated income paradoxically enables limited renewable energy adoption. However, weak policy enforcement, high upfront costs for solar PV, and socio-cultural inertia continue to hinder a large-scale energy transition (Chambalile et al., 2024; USAID A2C, 2021). Addressing this issue requires integrated policies that balance economic security with sustainable energy promotion. Hence, navigating the paradox of charcoal income supporting limited renewable energy adoption requires policies that holistically address socio-economic needs while enabling long-term sustainability transitions.

5.6.2 Deforestation from Charcoal Production

Charcoal production's environmental externalities, particularly deforestation, represent a growing threat to Zambia's forest ecosystems and rural sustainability. The study stresses the possible role of charcoal trade in driving deforestation in rural Zambia, revealing an accelerating environmental crisis (see Table 2). With increasing economic hardship and rising demand for charcoal, tree felling seems to have become indiscriminate, possibly leading to the depletion of key species, including those essential for biodiversity and ecosystem stability (Charcoal Burner FGD 2 (a, e)). The shift from selective harvesting of mature trees to cutting younger and fruit bearing trees illustrates the unsustainable nature of the trade, further exacerbating the depletion of forest resources (Charcoal Burner FGD 1 (b)). These findings align with existing literature, which shows that SSA loses approximately 0.7% of its total forest cover annually due to charcoal production (FAO-FRA, 2025; Nyarko et al., 2021; Sakala et al., 2023).

The impact of deforestation extends beyond energy supply and affects food security. As reported, key host trees for mopane worms, an important protein source, are being destroyed, jeopardising both ecological balance and rural livelihoods (Charcoal Burner FGD 1 (c)). Similar studies highlight that miombo woodlands, which cover nearly 45% of Zambia's landmass, are at high risk due to unsustainable charcoal production and agricultural expansion (Nansikombi et al., 2020b). Additionally, commercial farmers observe stark differences in forest depletion, with communal lands being severely degraded compared to private commercial farmland, where tree preservation efforts are more structured (Commercial Farmer Interview (g)). Despite these alarming trends, policy interventions remain insufficient. While some commercial farmers are adopting tree planting initiatives, the absence of government incentives and weak enforcement mechanisms hinder large-scale reforestation efforts (Commercial Farmer Interview (h, i); Moombe et al., 2020). Given that Zambia is among the top ten countries with the highest deforestation rates (Green Climate Fund (GCF), 2020; Ministry of Green Economy and Environment (MGEE), 2025; Nansikombi et al., 2020a; USAID A2C, 2021), urgent policy action is needed to regulate charcoal production, promote sustainable alternatives, and strengthen afforestation efforts (Commercial Farmer Interview (k); USAID A2C, 2021). These revelations highlight the urgent need for comprehensive regulatory frameworks and reforestation initiatives that address both environmental degradation and livelihood preservation.

5.6.3 Charcoal Profitability and Seasonality

The economic viability of charcoal production in Zambia is not uniform but fluctuates with seasonal, market, and climatic dynamics. The data in Table 3 reveals that charcoal trade in rural Zambia is highly seasonal, with profitability fluctuating due to climatic and economic cycles. Peak sales occur between June and July when cold temperatures drive higher demand for charcoal used in heating, bathing water, and poultry farming (Charcoal Burner Interview (a)). Similarly, in rural areas, disposable income rises during post-harvest months, leading to a temporary surge in charcoal purchases (Charcoal Burner FGD 2 (b)). However, profitability remains uneven across the value chain, with rural producers earning significantly less than urban retailers. This disparity is consistent with findings across SSA, where charcoal markets are structured in ways that disproportionately benefit intermediaries while keeping rural producers trapped in economic vulnerability (Rose et al., 2022).

During the rainy season, charcoal production declines due to logistical challenges such as wet kilns and increased risks of spoilage (Charcoal Burner FGD 2 (c)). This seasonal variation forces many rural producers to seek alternative income sources, including agricultural wage labour (Charcoal Burner FGD 1 (d)). However, these jobs are often temporary and insufficient to provide long-term financial stability. The limited diversification opportunities for rural charcoal producers highlight the urgent need for economic interventions that support alternative livelihoods (Chambalile et al., 2024; Steel et al., 2022). Market inefficiencies further disadvantage rural producers. On average, a 25m³ kiln generates a profit of approximately K800 ($32 US) per sale for the producer, while urban retailers make net profits of around K2,000 ($80 US) per sale (Charcoal Burner Interview (e)). This disparity perpetuates economic hardship, with many producers unable to escape the cycle of low earnings and dependency on charcoal burning (Charcoal Burner FGD 1 (f)). The lack of market regulation and inability to collectively bargain among producers due to the underground trade has led to exploitative pricing, reinforcing the economic constraints faced by rural households. These findings reinforce the need for policy interventions aimed at ensuring fair pricing mechanisms and strengthening producer cooperatives to enhance market competitiveness (Charcoal Burner FGD 1 (g); USAID A2C, 2021). These insights reinforce the importance of policy mechanisms that stabilise rural incomes and provide viable alternatives during off-peak charcoal production periods.

5.6.4 Solar Adoption and Income Diversification

Despite structural challenges, a gradual shift toward solar energy adoption suggests emerging opportunities for livelihood diversification in rural Zambia. The findings highlight an increasing shift towards solar energy adoption in rural Zambia, primarily driven by safety concerns, economic incentives, and the availability of financing mechanisms (see Table 4). Many rural households are transitioning from traditional lighting sources such as candles and kerosene lamps to solar-powered lighting due to its reliability and reduced fire hazards (Charcoal Burner FGD 1 (a)). This mirrors broader trends in SSA, where the affordability and accessibility of SHS have led to the widespread adoption of off-grid solar solutions, by extending study hours for school-aged children and reducing reliance on hazardous lighting alternatives, with more than 28 million systems installed across the region (Tinta et al., 2023).

Beyond lighting, solar-powered irrigation systems have emerged as an alternative livelihood strategy, allowing small-scale farmers to transition from charcoal burning to gardening and other agricultural activities (Charcoal Burner FGD 2 (b)). This aligns with studies indicating that access to solar irrigation can increase agricultural productivity by up to 300%, enhancing food security and income stability (Byaro et al., 2024). In Zambia, NGO-led initiatives are supporting smallholder farmers through credit-based solar irrigation schemes, enabling investments in boreholes and irrigation systems that can generate significant profits within a single farming season (Commercial Farmer Interview (c)). Despite these positive trends, financial barriers remain a significant impediment to the widespread adoption of solar technology. While basic lighting solutions are affordable, the high upfront costs of solar-powered irrigation and mechanisation limit broader adoption. Expanding microfinance schemes and subsidised credit facilities for productive solar systems is essential to accelerating rural energy transitions while reducing dependence on biomass fuels (Chambalile et al., 2024). Overall, the integration of solar PV into rural development must be supported by accessible financing and complementary agricultural interventions to scale its impact sustainably.

5.6.5 Financial Barriers and Charcoal Dependency

Financial exclusion remains a significant impediment to transitioning away from charcoal-based livelihoods toward renewable energy solutions. The testimonies demonstrate that economic constraints remain the primary barrier to a sustainable energy transition in rural Zambia (see Table 5). Charcoal production continues to serve as the dominant livelihood strategy for many households, driven by financial hardship, declining agricultural productivity, and limited employment opportunities (Charcoal Burner FGD 2 (b)). While awareness of deforestation and sustainability concerns exists, immediate economic needs take precedence over long-term environmental considerations (Charcoal Burner Interview (d)). This reflects broader trends in SSA, where 32% of rural households rely on charcoal as their primary income source (Chanda et al., 2025b; Steel et al., 2022).

The affordability of solar energy, particularly for productive applications such as irrigation and mechanisation, remains a significant challenge. While basic solar lighting systems are within financial reach for many households, larger systems for agricultural use require substantial investment, often exceeding local income levels (Charcoal Burner FGD 1 (a)). The high cost of solar technology has been identified as a key barrier to renewable energy adoption in SSA, with studies indicating that financing mechanisms, such as pay-as-you-go schemes and microloans, can significantly enhance affordability (Sadik-Zada et al., 2023). The findings suggest that a paradoxical relationship between charcoal income and solar adoption is evident, as many rural households reported that they use some earnings from charcoal sales to finance solar home system payments (Charcoal Burner FGD 2 (e)). Additionally, agricultural challenges further exacerbate financial constraints. The rising cost of fertiliser and declining government subsidies have increased production expenses, forcing farmers to supplement their income through charcoal burning (Charcoal Burner Interview (c, d)). This aligns with research indicating that declining soil fertility and the high cost of synthetic fertilisers have contributed to deforestation as farmers expand their cropland (Ngoma et al., 2021).

The poverty-environmental degradation nexus is a complex and debated issue in developing countries. Studies suggest a bidirectional relationship, where poverty can lead to environmental degradation and vice versa (Awad and Warsame, 2022; Duraiappah, 1999; Kassa et al., 2018). This cyclical relationship is particularly evident in Sub-Saharan Africa, where increased poverty correlates with deforestation and particulate matter (PM) 2.5 emissions (Ssekibaala and Kasule, 2023). Addressing these issues requires a multifaceted approach that enhances access to affordable fertilisers, promotes sustainable farming practices, and improves access to financing for renewable energy solutions (USAID A2C, 2021). Expanding financial support for solar photovoltaic (PV) adoption, particularly for productive uses, is essential to reducing dependence on charcoal in Zambia. Current solar financing models vary widely, with small lighting kits (two bulbs) costing K1,300 ($52 US) upfront or K1,700 in instalments over 54 weeks. Larger systems with lights, a radio, and a 32-inch TV are priced at K11,300 ($452 US) upfront or K16,000 in instalments over 78 weeks. Vendors such as My Sol, Fenix, Sun King, and Ready Pay collaborate with mobile network providers to offer these solutions (Charcoal Burner FGD 2 (e); Charcoal Burner Interview (f)). However, affordability remains a significant barrier, especially for productive solar systems. A 900W system costs K39,000 ($1,560 US) upfront or K48,200 in instalments over 26 weeks, while a 1,800W system, suitable for irrigation, costs K49,600 ($1,984 US) upfront or K74,000 ($2,960 US) in instalments over 78 weeks, placing them beyond the reach of most rural households (Charcoal Burner Interview (f)). Tackling these intertwined challenges will require multi-sectoral strategies that address both energy access and broader rural economic vulnerabilities.

5.6.6 Health Risks from Charcoal Usage

Beyond environmental and economic dimensions, the charcoal trade poses serious public health and safety risks to rural communities. The data highlight the substantial safety risks and negative consequences associated with charcoal production in rural Zambia (see Table 6). While charcoal burning remains a key economic activity, it exposes individuals to environmental, health, and social hazards. Unregulated kilns frequently lead to forest fires, particularly when handled by inexperienced burners (Charcoal Burner Interview (a)), exacerbating deforestation and loss of biodiversity. As demand for charcoal increases, tree depletion seems to have forced burners to cut fruit and medicinal trees, possibly impacting food security and traditional medicine availability (Charcoal Burner FGD 1 (b)). This aligns with broader research showing that over 250,000 hectares of forest are lost annually in Zambia, with charcoal production contributing significantly to this trend (USAID A2C, 2021).

Competition for limited forest resources has escalated conflicts over land ownership, leading to disputes among individuals and communities (Charcoal Burner FGD 2 (c); Charcoal Burner Interview (d)). This aligns with findings by Ngoma (2021) who indicated that in resource-scarce environments, competition for natural assets can result in increased land-related conflicts and legal uncertainties. Additionally, charcoal burners are often forced to venture deeper into forests to evade rangers, due to declining availability of appropriate trees, increasing exposure to occupational hazards such as venomous snake bites, which have resulted in fatalities (Charcoal Burner Interview (e); Charcoal Burner FGD 2 (f)). Health complications are also a major concern, with prolonged exposure to charcoal smoke causing chronic respiratory illnesses, including tuberculosis-like symptoms and persistent coughs (Charcoal Burner Interview (g); Charcoal Burner FGD 1 (h, i)). This mirrors global studies linking biomass fuel smoke inhalation to increased incidences of chronic obstructive pulmonary disease (COPD), asthma, and lung infections (Fullerton et al., 2011). Moreover, the charcoal trade has social consequences, with some men engaging in excessive alcohol consumption and unsafe sexual behaviour, increasing the risk of sexually transmitted infections (STIs) (Charcoal Burner Interview (j); Charcoal Burner FGD 2 (k)). Women, by contrast, are more likely to invest their earnings into household needs, education, and solar energy systems, suggesting gendered disparities in economic decision-making (Charcoal Burner Interview (j). Addressing these health and safety challenges necessitates cross-cutting interventions that include healthcare access, occupational safety, and transition support to cleaner energy alternatives.

5.6.7 Gender Roles in Charcoal Production

Gendered experiences within the charcoal value chain reveal deep inequalities that shape participation, benefits, and exposure to exploitation. The findings reveal significant gender disparities within Zambia's charcoal trade, where women face systemic barriers, socio-economic exclusion, and exploitative practices (see Table 7). While some women actively participate in charcoal production, their involvement is constrained by cultural norms, limited decision-making power, and economic vulnerabilities (Charcoal Burner Interview (c)). These findings align with broader research indicating that women in energy-related trades across Sub-Saharan Africa face structural gender biases that limit their access to resources, market opportunities, and financial independence (Bitzer et al., 2024; Ihalainen et al., 2020; Siakachoma, 2019; Tornel-Vázquez et al., 2024; Zulu et al., 2021). One of the key challenges women face in the charcoal business is financial dependency on male counterparts for labour, which significantly reduces their profit margins (Charcoal Burner FGD 2 (a)). Some women are subjected to transactional exploitation, where they are pressured into providing sexual favours in exchange for assistance with physically demanding tasks. Gendered economic disparities in the charcoal sector are further exacerbated by societal perceptions that consider charcoal burning a male-dominated trade, reinforcing discriminatory attitudes (Charcoal Burner Interview (d)).

Additionally, women in the charcoal business face unique biological challenges, particularly during pregnancy and breastfeeding, when physical labour becomes impossible. The absence of maternity leave or social support structures often forces women to temporarily either exit the trade, resulting in financial instability, or compromise childcare, endangering the health of children (Charcoal Burner FGD 1 (e)). Some single women resort to forming economic partnerships with men for survival, though not all adopt this strategy (Charcoal Burner FGD 1 (f)). Despite these barriers, women generally demonstrate more responsible financial management compared to their male counterparts, prioritizing household needs, education, and renewable energy investments (Charcoal Burner Interview (b)). As such, gender-sensitive policy responses are crucial for ensuring equitable access to energy opportunities and for protecting vulnerable groups from exploitation within informal energy economies.

5.6.8 Policy, Legal and Regulatory Gaps

Weak governance structures and regulatory enforcement have enabled the persistence of illegal and unsustainable charcoal production. Participant narratives suggest that systemic weaknesses in the regulation and governance of the charcoal trade in Zambia (see Table 8). While laws require permits for charcoal production, widespread non-compliance persists due to the high cost of permits, corruption, and ineffective enforcement mechanisms. Many charcoal burners avoid the formal licensing process and instead rely on informal arrangements, including bribery, to continue operations (Charcoal Burner Interview (a)). Corruption among law enforcement officers and forestry officials exacerbates the issue, with reports of arbitrary confiscation of charcoal, followed by resale for personal gain (Charcoal Burner FGD 1 (d)). These governance failures mirror trends observed in other Sub-Saharan African countries, where weak regulatory frameworks and informal economies contribute to unsustainable charcoal production and environmental degradation (Kabisa et al., 2019; Moombe et al., 2020; Zulu et al., 2021).

The high cost of permits discourages legal compliance, with some producers viewing restrictions as an unfair imposition on their livelihoods (Charcoal Burner Interview (b)). As a result, regulatory efforts to control deforestation remain largely ineffective, as truckloads of charcoal continue to reach urban centres without significant governmental intervention (Commercial Farmer Interview (g)). Furthermore, political considerations hinder stricter enforcement, as charcoal production is a significant livelihood source for rural populations, making stringent regulations politically risky (Charcoal Burner FGD 2 (i).,Branch et al., 2023; Cerutti et al., 2018). Chiefs and traditional leaders, who control large portions of communal land, also play a role in perpetuating illegal charcoal production for personal economic gain (Charcoal Burner FGD 1 (j)). The findings emphasise that regulatory efforts alone are insufficient without viable alternative energy sources and economic incentives to transition rural communities away from charcoal production. Without these, charcoal will remain an essential economic activity, regardless of legal restrictions (Charcoal Burner FGD 1 (h)). Thus, improving legal compliance will require not only stronger enforcement but also inclusive policies that provide viable and legal livelihood alternatives.

5.6.9 Urban Demand and Market Drivers

Urban energy poverty and consumer demand exert significant influence on rural charcoal production, forming an interdependent supply-demand dynamic. The responses suggest an intricate possible link between urban energy demand, economic drivers, and the sustainability of the charcoal trade in Zambia (see Table 9). Rural deforestation is partly driven by declining soil fertility, leading to agricultural expansion and an increased reliance on charcoal as a financial safety net (Charcoal Burner FGD 1 (a)). Additionally, seasonal variations, particularly during the rainy season, make charcoal production more challenging due to moisture exposure and compromised storage conditions, affecting supply consistency and market prices (Charcoal Burner Interview (b)). Urban demand remains a key factor sustaining the charcoal industry (Kabisa et al., 2019; Ngoma et al., 2019; Nyarko et al., 2021; Rose et al., 2022). While traditionally, charcoal was predominantly used by low-income peri-urban communities, worsening economic conditions and persistent load-shedding have led to increased reliance on charcoal across all geographies and socio-economic groups (Charcoal Burner FGD 2 (c), Rose et al, 2022). Recent hikes in the cost of living (Zambia Statistics Agency, 2025) and electricity tariffs (Chanda et al., 2025a; ZESCO, 2024) have further expanded the charcoal consumer base, making it a preferred alternative for both lower-income and middle-class urban households (Charcoal Burner FGD 1 (d)). These findings align with broader studies indicating that energy poverty in urban areas exacerbates deforestation in rural regions, as charcoal remains a cheaper and more accessible cooking fuel (Baltruszewicz et al., 2021; Ngoma et al., 2021; Tembo et al., 2015).

Despite growing demand, the profitability of charcoal production remains volatile due to increased market participation. More individuals have entered the trade, leading to price fluctuations and reduced earnings for rural producers (Charcoal Burner Interview (f); Charcoal Burner FGD 1 (g)). This trend has intensified competition among charcoal burners, further accelerating deforestation. Commercial farmers argue that the root cause of Zambia's charcoal problem lies not in rural areas but in urban energy policies, which fail to provide affordable and reliable electricity access (Commercial Farmer Interview (i, j)). Ultimately, the findings suggest that addressing Zambia's charcoal dependency requires urban-focused interventions. Expanding access to renewable energy in cities, subsidizing electricity for low-income households, and implementing incentives for clean cooking technologies could reduce charcoal consumption at scale. Without such measures, rural deforestation is likely to persist as long as urban demand remains high (Commercial Farmer Interview (k)). Hence, interventions aimed solely at rural producers will be insufficient unless complemented by urban energy reforms that reduce reliance on biomass fuels.

5.6.10 Socio-Political Dynamics of Charcoal

The role of socio-political actors, including traditional leaders and state institutions, adds a complex layer to the governance of charcoal production. The findings demonstrate the entrenched socioeconomic and political dynamics that sustain the charcoal trade in rural Zambia (see Tables 8 and 10). Despite regulatory efforts aimed at mitigating deforestation and promoting alternative energy sources, charcoal remains a vital economic pillar for many rural households. Chiefs and traditional leaders play a dual role in this trade, with some actively discouraging deforestation while others either participate or turn a blind eye due to economic hardships in their communities (Charcoal Burner Interview (a); Charcoal Burner FGD 1 (b)., Cerutti et al., 2018; Gumbo et al., 2013). These realities align with broader research indicating that traditional leadership structures often mediate access to natural resources, either facilitating sustainable management or enabling exploitation for economic survival (Zulu et al., 2022, 2021).

In April 2024, in alignment with the environmental sustainability goals outlined in Zambia's Eighth National Development Plan (8NDP), the Ministry of Green Economy and Environment (MGEE) announced a ban on charcoal burning in three districts with high production levels. Additionally, the ministry suspended the issuance of cordwood licences and permits, with plans to extend the ban nationwide (National Green Growth Strategy, 2024). However, empirical evidence from this study suggests that outright bans on charcoal production are neither practical nor enforceable without viable economic alternatives. Charcoal producers view such restrictions as a direct threat to their survival, equating these policies to an attack on their livelihoods (Commercial Farmer Interview (c)., Charcoal Burner FGD 2 (8i)). Furthermore, charcoal's role extends beyond lighting to heating, which is an essential household necessity for cooking and warmth (Commercial Farmer Interview (d)). This aligns with prior studies showing that energy transitions in Sub-Saharan Africa often fail due to a mismatch between policy prescriptions and local economic realities (Chanda et al., 2025a; Kapole et al., 2023; Szabó et al., 2021). Addressing these challenges requires a holistic approach that integrates community-led initiatives, economic incentives, and sustainable energy solutions. Without alternative income-generating opportunities, efforts to phase out charcoal production will likely face resistance, reinforcing continued environmental degradation. Effective transition strategies must therefore engage these actors through participatory governance and incentive-based community programmes.

5.6.11 Charcoal's Traditional and Cultural Importance

Charcoal's embeddedness in Zambia's cultural and traditional practices poses significant behavioural barriers to energy transition. The study highlights that firewood and charcoal are not merely sources of energy but integral components of Zambia's cultural and social fabric (see Table 11). Beyond cooking and heating, they serve as focal points for community interactions, family gatherings, and traditional customs. This deep-rooted cultural association presents a major challenge for energy transitions, as any shift to alternative energy sources must account for long standing social practices (Commercial Farmer Interview (a); (b)., Ibraimo et al., 2017). Research across Sub-Saharan Africa confirms that energy choices are not solely determined by economic or technological factors but are strongly influenced by cultural norms and daily routines (Moombe et al., 2020; Wang et al., 2022). Despite the availability of modern stoves and electrification in some rural areas, many households continue to prefer charcoal braziers due to their perceived social benefits (Commercial Farmer Interview (c)). The "imbaula" (charcoal brazier) culture is deeply embedded, making it difficult for households to abandon traditional fuels in favour of electricity or gas (Commercial Farmer Interview (d)). Comparative studies in regions like South Africa, where alternative biomass sources such as cow dung and maize cobs are used for heating, suggest that fuel substitution is possible but requires significant behavioural shifts (Commercial Farmer Interview (e)).

Beyond its role as a household fuel, charcoal serves significant medicinal and cultural functions in rural Zambia. It is widely used as a traditional remedy for poison ingestion, stomach ailments, and snake venom neutralization (Charcoal Burner FGD 2 (g); Charcoal Burner Interview (i)), which aligns with studies highlighting its adsorption properties in detoxification (Lee et al., 2019; Zaini and Mohamad, 2015). Additionally, charcoal holds deep cultural significance, as it is used in rituals to ward off evil spirits, prevent bad dreams, and protect ubunga (corn flour or mealie meal) from supernatural theft (Charcoal Burner FGD 1 (h)). This aligns with research by Chikumbirike and Bamford (2021), who document its symbolic use in African spiritual practices. Historically, charcoal was buried with individuals who suffered tragic deaths or were barren to prevent perceived curses from recurring in future generations (Charcoal Burner FGD 1 (h)). The persistence of these cultural practices highlights the need for energy transition policies that integrate social dimensions alongside technological and economic considerations. Simply introducing alternative fuels without addressing behavioural and cultural barriers is unlikely to yield sustainable adoption (Samboko et al., 2016; Zulu et al., 2021). Instead, community-driven energy education, culturally sensitive interventions, and hybrid energy solutions that align with traditional practices may facilitate smoother transitions. Subsequently, policies must move beyond technical solutions to include culturally attuned education and behavioural change campaigns.

5.6.12 Challenges to Efficient Cooking Technology

Adoption of improved cooking technologies remains limited due to perceived inefficiencies, cultural preferences, and gender-based constraints. The findings reveal that despite efforts to promote energy efficient cooking technologies, their adoption in rural Zambia remains low due to cultural preferences, gender roles, and technical inefficiencies (see Table 12). Many households continue to rely on firewood and charcoal because alternative stoves do not match the heating capacity required for staple foods like nshima (Charcoal Burner FGD 1 (b)). This aligns with the findings of Ibe and Kollur (2024) and Phillip (2023), who argue that the perceived inefficiency of improved cooking stoves contributes to their rejection in many Sub-Saharan African communities. Some participants even abandoned free energy efficient braziers due to their inability to generate sufficient heat, highlighting the importance of functionality in energy transition efforts (Commercial Farmer Interview (a)).

Safety concerns also influence cooking technology choices. While some women acknowledge the risks associated with firewood collection, including security threats and encounters with wild animals (Charcoal Burner Interview (f)), they remain hesitant to transition to new cooking methods unless these alternatives meet their heating and cooking needs. This is similar to the findings of Phillip (2023), Sesan (2012) and Tornel-Vázquez (2024), who note that safety considerations alone are often insufficient to drive the adoption of alternative cooking technologies unless they align with users' practical needs. Furthermore, gender roles play a significant part in stove preferences, with women fearing domestic conflicts if food preparation takes longer (Charcoal Burner FGD 1 (d)). This reflects the conclusions of Phillip (2023), Sovacool and Griffiths (2020) and Yunusa (2023), who highlight that energy transitions must account for the social and cultural dimensions of household cooking habits. Nonetheless, initiatives such as the North Swaka Project, which promotes maize cob charcoal as a viable alternative, indicate that when new technologies align with cultural expectations and practical demands, adoption rates improve (Commercial Farmer Interview (h)., Adhikari et al., 2025). Sustainable energy transition strategies must prioritise culturally appropriate technologies that offer equal or superior performance compared to traditional fuels. Consequently, innovation in cooking technologies must be driven by local user needs and socio-cultural realities to ensure effective uptake.

5.6.13 Charcoal's Environmental and Economic Costs

While charcoal offers short-term economic relief, its long-term environmental and economic consequences are becoming increasingly unsustainable. The findings highlight that charcoal production remains a crucial economic activity in rural Zambia, particularly during the agricultural off-season when alternative income opportunities are scarce (see Table 13). Many individuals engage in charcoal burning as a supplementary livelihood, especially at the start of the farming season when land is cleared for cultivation (Charcoal Burner FGD 1 (a)). This aligns with the findings of (USAID A2C, 2024 & 2021), which estimates that charcoal production contributes to 25% of Zambia's annual deforestation, contributing to the 180,000 - 250,000 hectares of forest loss per year. Despite this significant environmental impact, the high urban demand for charcoal seems to continue to drive production, outpacing the rate of natural forest regeneration (Charcoal Burner FGD 1 (d)., Kabisa et al., 2019; Mulenga et al., 2019; Rose et al., 2022). Charcoal production is a labour-intensive process requiring skill and close monitoring. Kilns can take up to three weeks to complete, and any lapse in attention can result in losses (Charcoal Burner FGD 2 (b); (c)). This is similar to the findings of (Gumbo et al., 2013; Njenga et al., 2023), who emphasise that inefficiencies in traditional charcoal-making techniques not only contribute to environmental degradation but also limit economic gains for producers. The reliance on large trees for production, with each 25m^3 kiln requiring around 10 trees, further accelerates deforestation (Charcoal Burner FGD (e)). Despite this, replanting efforts remain rare, as many charcoal burners believe forests regenerate naturally (Charcoal Burner FGD 1 (d)). This aligns with the conclusions of Zulu (2021), who highlights that a lack of awareness and incentives for reforestation exacerbates unsustainable harvesting practices.

Financial constraints significantly influence charcoal production patterns in Zambia. Both trees and charcoal are undervalued, making unsustainable harvesting economically attractive. The cost of acquiring trees for a single kiln can be as low as K500 ($20 US) for 10 trees, each approximately 7 metres in height, with individual trees valued at around K100 ($4 US) (Charcoal Burner FGD (f)). The undervaluation extends to renewable energy options, as it takes the equivalent of 20 trees (two kilns) worth of charcoal to afford a basic two-bulb solar lighting system (see Fig. 5 and 6). Despite the relatively low cost of raw materials, charcoal producers often struggle to secure fair market prices due to increased competition and the dominance of middlemen in the supply chain. This aligns with the findings of Lyambai (2017) and Sumba (2021), who highlight that economic vulnerabilities prevent producers from adopting sustainable practices. These dual costs necessitate a revaluation of both charcoal and renewable alternatives to shift economic incentives toward sustainability.

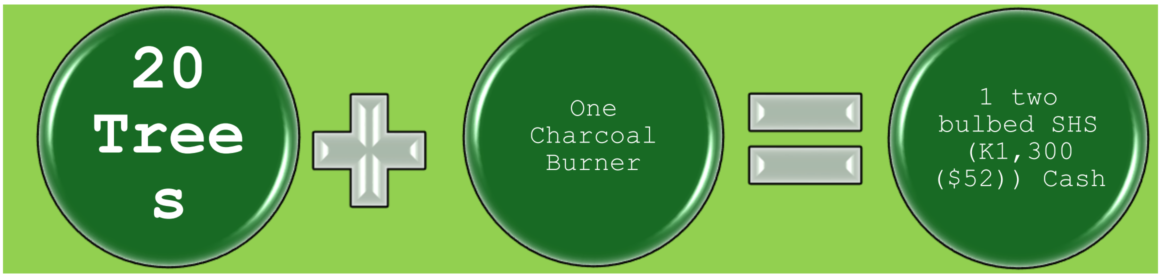

Figure 5: Tree-to-solar economic trade-off ratio (Cash) (Author, 2025)

Figure 6: Tree-to-solar economic trade-off ratio (Instalments) (Author, 2025)

5.6.14 Actual and Potential Carbon Loss

Charcoal related deforestation has resulted in substantial carbon stock loss, significantly impacting Zambia's climate mitigation capacity. The findings indicate a significant increase in charcoal attributed carbon stock loss in Zambia, with 67,068,795 tCO_2 lost between 2008-2015 and rising to 116,067,687 tCO_2 between 2016-2023 (see Table 14). Among the four study districts, Mkushi exhibited the highest carbon stock loss, increasing from 2,185,374 tCO_2 to 4,408,780 tCO_2 in the respective periods. Conversely, Chingola experienced the lowest loss, with 606,256 tCO_2 between 2016 and 2023. This trend aligns with findings in Ghana, where unsustainable charcoal production depletes half of standing tree stock per site annually (Arko et al., 2024), stressing the severe impact of charcoal-driven deforestation.

The study further estimated that Zambia's lost annual carbon sequestration potential, attributable to charcoal-related forest loss, increased from 1,541,811 tCO_2 per year (2008-2015) to 2,668,223 tCO_2 per year (2016-2023). Mkushi recorded the highest sequestration loss at 101,351 tCO_2 per year. Similar trends are observed in Ethiopia, where charcoal production contributes to the loss of over 71,000 trees annually, accelerating land degradation (Gebremeskel, 2023). These findings highlight the urgent need for enhanced forest conservation policies. The data reinforces the urgency of integrating forest conservation into national energy policy and climate commitments.

5.6.15 The Charcoal - Solar Paradox (CSP) Cycle

The Charcoal - Solar Paradox (CSP) Cycle illustrates the contradictory relationship between biomass-based livelihoods and renewable energy adoption. The CSP cycle highlights the paradox where charcoal earnings enable limited solar PV adoption while simultaneously fueling deforestation, economic vulnerability, and energy poverty (see Fig. 7).

a) Seven Stages of the RUDSHAM Charcoal-Solar Paradox Cycle

1) Resource Exploitation: Traditions, economic and energy poverty and urban charcoal demand drive rural communities to clear healthy forests for charcoal production, leading to deforestation and biodiversity loss.
2) Agricultural Expansion and Reinforcement: Land clearing for farming introduces new entrants to the charcoal trade, further entrenching deforestation and creating a self reinforcing cycle.
3) Unregulated Charcoal Trade: The charcoal industry operates informally, contributing to greenhouse gas emissions, land degradation, and weak enforcement of sustainable practices.
4) Dependency on Charcoal Income: Many rural households rely on charcoal sales as their primary livelihood, making it difficult to shift to alternative economic activities which are mostly do not exist. Furthermore, cost of living challenges exacerbate demand as well as production.
5) Household-Level Solar Adoption: Some charcoal income is reinvested in basic solar lighting (e.g., phone charging and household illumination), but remains insufficient for productive energy use trapping them in perpetual cycles of poverty.
6) Solar PV Affordability Barrier: High upfront costs prevent widespread adoption of solar PV for irrigation, mechanization, and other productive applications, limiting energy transition potential.
7) Missed Sustainable Transition: Without targeted interventions, reliance on charcoal persists, preventing a full shift to renewable energy and reinforcing continued environmental and economic vulnerabilities.

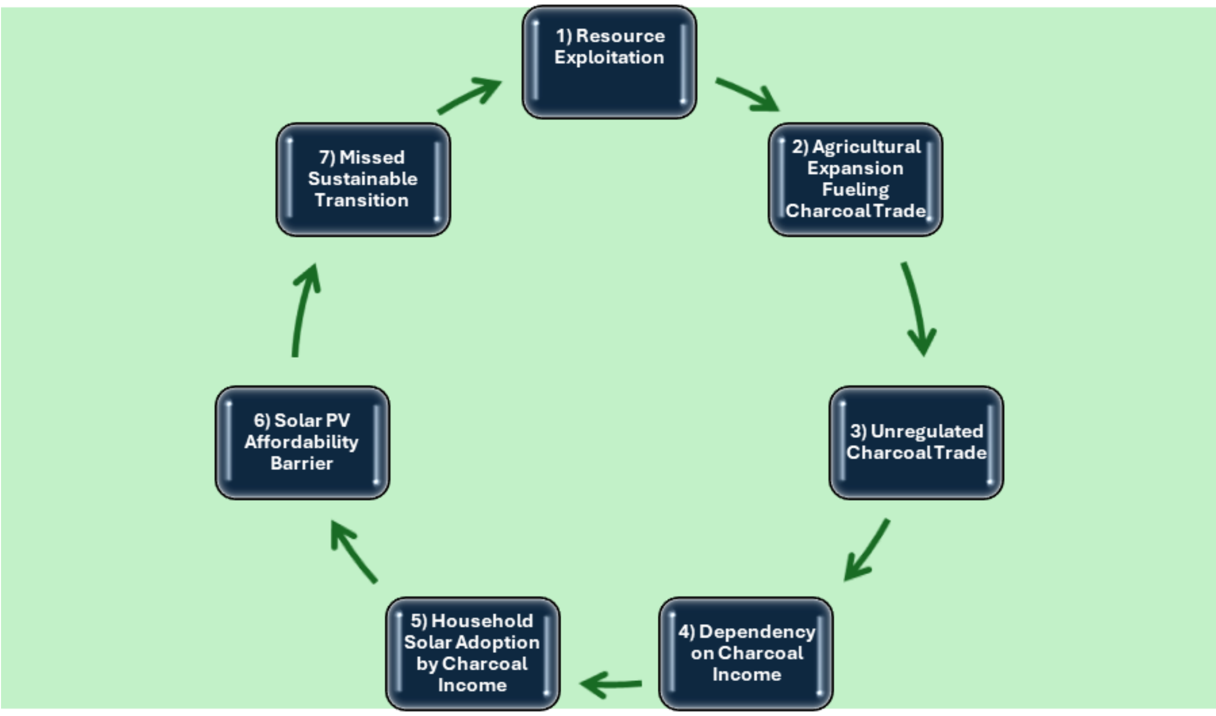

Figure 7: Charcoal-Solar Paradox (CSP) Cycle

Addressing this paradox requires systemic interventions that integrate economic resilience, environmental protection, and energy access in a unified policy framework.

b) The RUDSHAM Charcoal-Solar Paradox in pictures

The RUDSHAM Charcoal-Solar Paradox in pictures (see Fig. 8) illustrate various stages of the charcoal trade: healthy forests (a–c), the charcoal production process (d–l), packaging and selling by producers (m–n), retail sales in urban areas (o), charcoal income contributing to solar PV adoption in rural areas (p–q), and environmental degradation (r), including deforestation (d–f), greenhouse gas emissions from burning wood (j–l), and carbon absorption loss (d–f).

Pictures a–r depicting the RUDSHAM Charcoal-Solar Paradox (by author)

Figure 8: Pictures a–r depicting the RUDSHAM Charcoal-Solar Paradox (by author)

5.7 Policy Recommendations

The following policy recommendations are informed by the study's empirical findings and thematic discussion, which highlighted complex intersections between energy poverty, rural livelihoods, governance gaps, deforestation, and socio-cultural dynamics. Each recommendation is rooted in specific observations from the charcoal and solar adoption discourse presented earlier.

5.7.1 Support Livelihoods to Reduce Charcoal

Grounded in the study's findings on economic dependence and seasonality (Section 5.6.1 & 5.6.3), this recommendation addresses the critical need to diversify rural income streams that currently hinge on unsustainable charcoal production. The Ministry of Green Economy and Environment and the Ministry of Small and Medium Enterprises Development should promote alternative income sources such as agro-processing, eco-tourism, and sustainable timber production. WWF Zambia and USAID A2C should expand microfinance initiatives to support small businesses, reducing reliance on charcoal. Addressing rural income insecurity remains politically sensitive but essential for shifting communities away from ecologically destructive charcoal economies.

5.7.2 Strengthen Forestry Governance and Management

Drawing on the findings in Sections 5.6.2 and 5.6.8, which reveal the weakness of enforcement mechanisms and the depletion of forest cover due to illegal harvesting, this recommendation aims to enhance institutional oversight and incentivise reforestation. The Forestry Department must enforce reforestation mandates for charcoal producers and combat illegal deforestation through stricter regulations. Collaborations with ZEMA, UN-REDD, and FAO should promote carbon credit incentives and afforestation programmes. Community-led forestry management will ensure sustainability while allowing regulated charcoal production. Strengthening forestry governance should include support for community-managed woodlots using fast-growing species to meet charcoal demand sustainably. Political will is needed to decentralise forestry control, which often faces institutional resistance and contestation over land-use rights.

5.7.3 Expand Solar and Alternative Fuel Access

Based on Sections 5.6.4 and 5.6.5, which highlight the Charcoal – Solar Paradox and financial constraints, this recommendation underscores the necessity of expanding affordable access to solar PV systems for productive and domestic use. The Ministry of Energy should prioritise financial support for solar PV adoption, particularly in rural areas. Expanding microfinance for solar-powered irrigation and productive-use technologies will enhance energy access. NGOs such as BGFA and SolarAid Zambia should facilitate affordable off-grid solar solutions and improved biomass stoves. Policy coordination across ministries and donor agencies remains fragmented, limiting solar deployment and raising questions about long-term energy justice.

5.7.4 Improve Market Regulation and Pricing

This recommendation responds to the structural market inequalities identified in Section 5.6.3, which documented profit disparities across the charcoal value chain, often to the detriment of rural producers. The Ministry of Commerce, Trade, and Industry should implement fair pricing regulations by strengthening producer cooperatives and reducing intermediary exploitation. ZAFFICO and IUCN should introduce sustainable charcoal certification programmes, incentivising eco-friendly production and discouraging unsustainable harvesting. Reforming charcoal markets entails confronting vested interests and informal networks that benefit from regulatory ambiguity and weak enforcement.

5.7.5 Address Gender Disparities in Energy

Emerging from the gender-based analysis in Section 5.6.7, this recommendation reflects the need to redress gender inequities in energy production, access, and income distribution. The Ministry of Gender and Child Development, UN Women Zambia, and AWEEF should provide financial and vocational training programmes for women in clean energy enterprises. Micro-credit facilities and gender-focused policy frameworks should prevent economic exploitation and expand women's participation in renewable energy. Mainstreaming gender equity in energy policy requires overcoming systemic biases in planning, budgeting, and implementation across male dominated institutions.

5.7.6 Improve Urban Energy and Reduce Charcoal

This recommendation is informed by Section 5.6.9, which linked high urban demand for charcoal to unreliable and unaffordable electricity services in Zambia's towns and cities. The Ministry of Energy, in collaboration with ZESCO and ERB, should introduce subsidised electricity tariffs, prepaid metering, and increased investment in mini-grid solar solutions. The World Bank, USAID, and UNDP should support clean cooking initiatives, including subsidised LPG, to reduce urban charcoal dependency. Urban energy transitions demand balancing affordability, grid reliability, and political resistance to subsidy reforms within constrained fiscal contexts.

5.7.7 Promote Energy-Efficient Cooking Adoption

Stemming from Sections 5.6.12 and 5.6.6, which highlighted health risks and stove inefficiencies, this recommendation addresses both technical and behavioural obstacles to clean cooking transitions. The Ministry of Science and Technology, NISIR, and GIZ should support the development of culturally adaptable energy efficient stoves. Awareness campaigns on the economic and health benefits of improved cookstoves should drive behavioural change, reducing reliance on biomass fuels. Policy inertia and lack of scale-up funding challenge widespread adoption, despite technical viability and strong evidence of health benefits.

5.7.8 Embed Sustainability in Education and Awareness

Grounded in the sociocultural and behavioural insights from Sections 5.6.10 and 5.6.11, this recommendation advocates for a long-term educational strategy to reshape energy practices from a young age. The Ministry of Education should integrate sustainability studies from preschool onwards and conduct awareness campaigns via radio, TV, and social media. Donor partnerships should fund community-based environmental education programmes to highlight the consequences of deforestation and promote alternative energy solutions. Embedding sustainability in education requires navigating curricular rigidity and limited teacher training budgets, especially in under-resourced rural schools.

5.8 Conclusion

5.8.1 Key Findings and Knowledge Contributions

This study introduces the RUDSHAM Charcoal - Solar Paradox (CSP), revealing how charcoal income paradoxically facilitates solar PV adoption in rural Zambia while simultaneously driving deforestation. This novel insight underscores the need for integrated energy and environmental policies that promote renewable energy financing while mitigating deforestation.

A major finding is that urban demand, rather than rural supply, seems to sustain the charcoal trade. Erratic electricity supply, economic constraints, and high tariffs force urban households to rely on charcoal for cooking and heating. Thus, urban focused interventions, expanding electricity access and clean cooking solutions, are crucial for reducing rural deforestation.

Applying the RUDSHAM framework, this study is the first to holistically examine the behavioural, economic, and regulatory drivers of energy transitions in Zambia. It demonstrates that agricultural land clearing acts as a gateway to charcoal dependence, necessitating policies addressing both deforestation and farming expansion.

Gender disparities persist, with women earning significantly less and facing financial exclusion in the charcoal trade. Structural reforms are required to promote equitable economic participation. The study further reveals that the socio-economic and environmental impacts of charcoal production are inadequately recognised, as rural producers derive minimal benefits while intermediaries capture disproportionate gains, exacerbating poverty, social exclusion, and deforestation. Addressing these sustainability concerns requires fair pricing systems and inclusive producer cooperatives. Finally, findings highlight that 20 trees are required to produce charcoal equivalent to purchasing a basic solar lighting system, reinforcing the urgency for improved solar financing and alternative livelihoods to reduce charcoal dependency.

5.8.2 Future Research Directions

Future research should focus on longitudinal assessments of energy transition policies, particularly examining the long-term economic impacts of solar PV adoption on charcoal-dependent households. Additionally, gender dynamics in the charcoal trade warrant deeper investigation, particularly regarding the financial barriers women face in transitioning to alternative livelihoods. Another key area for further research is the effectiveness of urban energy policies in reducing charcoal demand.

Chapter 6: The African clean energy-deforestation paradox: Examining the sustainability trade-offs of rural solar energy expansion in Zambia. (Article 2)

Status: Published - Energy Research and Social Science Journal

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Summary: This article explores the paradoxical consequences of rural solar photovoltaic (PV) expansion in Zambia, where adoption is often financed through ecologically harmful activities such as charcoal production, forest clearing, and unsustainable harvesting of non-timber forest products (NTFPs). It identifies a critical sustainability trade-off: the income used to acquire solar systems often derives from practices that degrade forest ecosystems, thereby undermining the environmental rationale behind renewable energy transitions.

Abstract: Findings expose a major policy disconnect between Zambia's renewable energy strategies and forest governance. Charcoal burning, bark stripping, and the extraction of resources like honey and mopane worms, while vital to rural livelihoods, contribute to deforestation and biodiversity loss. These activities are driven not by ignorance, but by necessity, households seek immediate cash to purchase small solar systems, often for lighting or phone charging. The research challenges linear clean energy narratives and instead presents solar adoption as a process embedded in ecological and financial trade-offs.

Recommendations: Recommendations include the alignment of clean energy initiatives with forest conservation strategies and the introduction of alternative, sustainable financing models.

Overall contribution: This article contributes to Thesis Objectives 1 and 5 by highlighting the complex interlinkages between energy access, environmental degradation, and rural livelihoods. The article strengthens the thesis's overall argument that Zambia's energy transition must be viewed holistically, balancing renewable energy promotion with ecological resilience and local economic realities.

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Keywords: Solar PV Adoption, Clean Energy–Deforestation Paradox, Sustainability Trade-offs, Environmental Justice, Renewable Energy Financing

6.1 Introduction

6.1.1 Background

Sub-Saharan Africa (SSA) remains one of the most energy-deprived regions globally, with over 600 million people lacking access to electricity (Chanda et al., 2025a; M. Santos et al., 2023). This persistent energy poverty has spurred growing international and domestic interest in clean, decentralised solutions such as solar photovoltaic (PV) systems. Solar PV technology is increasingly seen as a viable tool for achieving the twin goals of expanding energy access and reducing carbon emissions (Nygaard et al., 2016; Pillot et al., 2017).

Across SSA, innovations such as pay-as-you-go (PAYG) systems and mobile-enabled smart metering have supported the uptake of pico and small-scale PV solutions, particularly in rural areas where extending the national grid is economically and logistically challenging (Nygaard et al., 2016). This decentralised model holds particular promise in countries like Zambia, where only 25% of the population, and less than 6% of rural households have electricity access (Budzianowski et al., 2018; Chambalile et al., 2024; Chanda et al., 2025b; ERB, 2024).

However, this optimistic narrative is often accompanied by significant challenges. High upfront costs, inadequate infrastructure, technical skill shortages, and system maintenance issues have slowed progress and limited solar PV's full potential (M. Santos et al., 2023). While the clean energy transition is vital, its success hinges on deeper understanding of the social, economic, and environmental dynamics at play, particularly in rural contexts.

6.1.2 The Deforestation - Solar Nexus in Zambia

Globally, deforestation has reached alarming levels, with an estimated 1.5 billion hectares of forest cover lost over the past 300 years (Ritchie, 2021). In particular, SSA remains vulnerable, recording deforestation rates higher than the global average (Diarrassouba and Boubacar, 2009; Yalew, 2015). According to the Food and Agriculture Organization, the world loses about 13 million hectares of forest annually, with Africa accounting for a significant portion of this decline (Diarrassouba and Boubacar, 2009). Despite this urgency, the drivers of deforestation in SSA remain contested, as factors such as population density, rural poverty, and industrial logging do not consistently explain forest loss across the region (Yalew, 2015).

Zambia provides a particularly complex and instructive case within SSA. The country experienced a 10% reduction in forest area and a 25% increase in cropland between 2000 and 2018, reflecting ongoing tension between environmental conservation and rural livelihoods (Phiri et al., 2023). Charcoal production is a primary deforestation driver, constituting a key income source for many rural households (Mwitwa, 2012; Richardson et al., 2021). Likewise, subsistence agriculture, especially shifting cultivation, continues to cause widespread forest clearance (Holden, 1997; Ngoma et al., 2019). Less visible yet ecologically consequential practices also contribute to forest degradation, though they often remain unaccounted for in official assessments (Chungu et al., 2007; Guedje et al., 2016; Van Stan et al., 2021). While many of these practices have historically sustained rural economies, their role in enabling access to modern energy introduces a complex sustainability dilemma. Crucially, many of these forest based economic activities seem to be linked to the funding of solar PV installations (Chanda et al., 2025b, 2025c; Tinta et al., 2023; Wassie et al., 2021; Wassie and Adaramola, 2021). In the absence of accessible credit or subsidies, rural households often resort to charcoal sales, timber extraction, or non-timber forest product (NTFP) collection to raise the funds needed to purchase solar lighting systems or mobile charging kits. Thus, in a paradoxical twist, clean energy adoption is inadvertently accelerating environmental degradation, a phenomenon this study refers to as the "Clean Energy - Deforestation Paradox."

6.1.3 Policy Gaps and Missed Synergies

Zambia's national policy frameworks have not adequately addressed this paradox. Energy and environmental policies are developed in silos, leading to fragmented implementation (Ajagun et al., 2024; Banik, 2021; Guo et al., 2023). Energy policies typically focus on expanding solar PV access without considering how rural communities finance such technologies (Moner-Girona et al., 2022; Sovacool, 2013). Likewise, forest conservation programmes, such as REDD+, rarely factor in the energy demands of rural households, despite their heavy dependence on forests for both income and domestic energy (Ratnasingam et al., 2014). This disconnection results in missed synergies. For instance, rural electrification policies in Zambia lack integrated financing models tailored to low-income, forest dependent communities (Chambalile et al., 2024). Public-private partnerships and donor funded interventions have made some progress but often fail to reach the poorest, who remain excluded from sustainable energy access while continuing to rely on unsustainable income strategies. In effect, Zambia and by extension much of SSA, is facing a sustainability paradox. Renewable energy adoption is promoted as a climate solution, yet its uptake, in the absence of inclusive financing and integrated policy, is contributing to forest loss and environmental degradation.

6.1.4 Research Problem and Aim

This study seeks to critically examine the sustainability trade-offs of rural solar PV expansion in Zambia. While solar PV is globally recognised as a clean technology, its financing mechanisms in rural Zambia have yet to be scrutinised for their potential environmental costs. The central research problem focuses on the possibility that some rural households finance solar PV systems through income derived from deforestation related activities. The primary aim is to examine how such income contributes to solar adoption and to reflect on the broader sustainability implications of this financing model.

6.1.5 Research Objectives

To achieve this aim, the study sets out the following objectives:

- To identify both major and minor drivers of deforestation in rural Zambia, including under-researched practices.
- To examine the financing strategies employed by rural households to acquire solar PV systems, with a focus on forest-based income streams.
- To examine the socio-environmental trade-offs of solar adoption, particularly where renewable energy transitions may inadvertently rely on harmful environmental practices.
- To propose policy recommendations that support clean energy transitions in a manner that is both environmentally sustainable and socially just.

6.1.6 Research Questions

This study seeks to address the following research questions:

- What are the main, and often overlooked, drivers of deforestation within rural Zambia?
- What financing mechanisms are respondents using to adopt solar PV systems?
- To what extent, and in what ways, might this financing depend on forest exploitation?
- What policy interventions are required to mitigate potential tensions between clean energy access and environmental sustainability?

6.1.7 Study Gaps and Contribution

Most existing literature on deforestation in Zambia has focused on large-scale drivers, such as commercial agriculture and logging (Holden, 1997; Ngoma et al., 2019; Richardson et al., 2021). Similarly, studies on solar PV tend to highlight its climate mitigation benefits, without examining the financial behaviours enabling uptake among rural users (Nygaard et al., 2016; Sakala et al., 2023).

This study contributes to bridging these gaps by offering a multi-dimensional perspective that links rural energy transitions with forest exploitation at the household level. It is among the first to interrogate the social and environmental costs of grassroots clean energy adoption, focusing specifically on the micro-economies that underpin solar PV expansion in off-grid communities. In doing so, it builds on but also critiques the current sustainability discourse, arguing that focusing solely on end-use outcomes (i.e., cleaner energy) risks overlooking the damaging processes through which those outcomes are achieved.

6.1.8 Why a Holistic Approach is Necessary

Sustainability cannot be judged solely by outcomes. It must consider the entire lifecycle and context of technological adoption. A solar lantern that displaces kerosene is undoubtedly a cleaner alternative, but if it is financed through charcoal production or unsustainable harvesting of forest bark, its net sustainability becomes questionable. Forest degradation contributes to biodiversity loss, microclimate changes, and diminished ecosystem services, all of which negatively affect the very rural communities these technologies aim to serve (Mohammed, 2020; UN-REDD+, 2024). Moreover, the decline in forest cover undermines agricultural productivity, increases fire risks, and diminishes rainfall, thus compounding the vulnerabilities of already marginalised populations (Khan, 2023). By drawing attention to these interconnected challenges, this study promotes a holistic and integrated framework for evaluating sustainable energy transitions. It highlights the urgent need to reconcile the goals of energy access and environmental conservation. It reveals a largely overlooked trade-off in rural Zambia's clean energy story.

6.2 Literature Review

6.2.1 Deforestation and Ecological Stability

Environmental degradation continues to threaten ecosystem stability across SSA, with Zambia's Miombo woodlands standing out as particularly vulnerable (Ngoma et al., 2024). As climate variability intensifies, trophic interactions within ecosystems are increasingly destabilised, triggering cascading effects such as biodiversity loss and habitat fragmentation (Tovar-ortiz and Rodriguez-gonzalez, 2024). These ecological disturbances signal the need for integrative development strategies that consider long-term sustainability and resilience rather than short-term economic gains. Deforestation in Zambia exemplifies such anthropogenic pressure. The country is losing an estimated 250,000 to 300,000 hectares of forest annually (Phiri et al., 2019). Between 2001 and 2023, Zambia lost 2.44 million hectares of tree cover, resulting in over 911 Mt of CO_2 emissions (GFW, 2025). These changes are not only detrimental to biodiversity but also compromise soil structure, water cycles, and climate stability.

6.2.2 Fertiliser Use and Agricultural Practices

A critical but often overlooked environmental pressure in Zambia is the widespread use of chemical fertilisers. While these inputs have been vital in addressing food security by boosting crop yields (Pahalvi et al., 2021), their adverse effects on soil and water systems are well documented (Singh, 2018; Verma, 2015). Excessive nitrogen application contributes to greenhouse gas emissions, acidification, and the loss of soil organic matter (Tyagi et al., 2022; Walling and Vaneeckhaute, 2021). Moreover, smallholder farmers in Zambia frequently prioritise immediate returns over environmental sustainability, continuing to rely on synthetic fertilisers even when aware of the risks (Mubanga and Bwalya, 2020). This illustrates a broader trend where short-term adaptation strategies are adopted at the expense of long-term ecosystem resilience.

6.2.3 Forest Loss and Underlying Drivers

Deforestation in Zambia is shaped by both direct and structural factors. Agricultural expansion, especially shifting cultivation, remains the dominant driver (Richardson et al., 2021). Smallholder farmers alone account for approximately 60% of forest loss (Ngoma et al., 2019). Notably, the Jevons Paradox appears more applicable than the Borlaug hypothesis in this context, as yield enhancing technologies are correlated with further land conversion rather than conservation (Goulart et al., 2023). Charcoal production and timber harvesting are also substantial contributors to forest degradation (Day et al., 2014; Gumbo et al., 2013). The extraction of valuable tree species, such as Mukula and Zambezi Teak, for international trade is often facilitated by weak legal enforcement and institutional corruption (Forest Trends, 2021). Compounding these pressures are subtle yet significant drivers like bark stripping for medicinal use, artisanal wood harvesting, and small scale clearing for fencing or firewood, all of which contribute to forest degradation but are largely invisible in conventional land-use data (Chungu et al., 2007; Guedje et al., 2016).

6.2.4 Biomass Energy Contradictions and Dependency

Despite advancements in solar energy technologies, Zambia remains overwhelmingly dependent on biomass for household energy. In rural areas, 81.9% of households use firewood, and 13.2% use charcoal whilst in urban settings, 73% of households rely on charcoal (ZamStats, 2022). Traditional earth kilns, widely used in charcoal production, consume around eight tonnes of wood to produce just 1.3 tonnes of charcoal. In contrast, steel kilns can achieve conversion efficiencies of approximately 2.4:1 (Tazebew et al., 2023), more than double that of earth kilns. This highlights the significant inefficiency and severe ecological costs associated with traditional methods (Gumbo et al., 2013). Paradoxically, income generated from the sale of charcoal and other forest products is often used to finance solar PV systems technologies promoted precisely to mitigate the environmental damage these income streams exacerbate. This contradiction highlights a complex interplay between clean energy adoption and environmental harm, reinforcing the notion of a Clean Energy - Deforestation Paradox (Kazungu et al., 2020).

6.2.5 Ecological and Public Health Effects

Deforestation's impacts go beyond carbon emissions and biodiversity loss. In Zambia’s Kamfinsa sub-catchment, forest area declined from 13,430.5 ha in 1990 to just 2,904.7 ha in 2010, leading to soil erosion and carbon emissions valued at over US$300 per hectare annually (Kasaro et al., 2019). Disruptions to ecosystem services such as pollination, seed dispersal, and water retention further threaten agricultural and ecological stability (Raj et al., 2022). Moreover, forest degradation is increasingly linked to public health crises. In Sub-Saharan Africa, deforestation has been correlated with elevated malaria prevalence, especially among children in poorer households (Estifanos et al., 2024). The disruption of forest habitats influences the breeding conditions for malaria vectors, exacerbating health inequalities and creating additional socio-economic burdens.

6.2.6 Governance Failures and Policy Fragmentation

Zambia’s deforestation crisis is intensified by weak governance and disjointed policy frameworks. Despite legal reforms such as the Forest Act No. 4 of 2015, enforcement remains sporadic and under resourced (CSO, 2018; Kalaba, 2016). REDD+ initiatives, although promising, often operate within private tenure systems that exclude community voices and fail to address local needs (Manda and Mukanda, 2023). These shortcomings are compounded by corruption, which undermines transparency and accountability in forest resource management (Moreira-Dantas and Söder, 2022). Sectoral silos further weaken efforts to address deforestation. Energy policies seldom integrate forest conservation priorities, while forestry policies neglect the energy demands of rural populations (Ratnasingam et al., 2014). As a result, clean energy interventions risk reproducing environmental injustices if not embedded within cross-sectoral sustainability frameworks.

6.2.7 Broader Socioeconomic Trade-offs Beyond Forests

Forest loss in Zambia is closely intertwined with poverty, inequality, and livelihood insecurity. Forests provide critical resources such as honey, mushrooms, caterpillars, and construction materials (Anyango et al., 2018; Chanda et al., 2025b, 2025c; Kasaro et al., 2019). Their degradation, therefore, has cascading effects on nutrition, health, and income stability (Carpio-Domínguez, 2024). At a macro level, deforestation contributes to shifts in microclimates, reduced rainfall, and declining agricultural productivity, all of which jeopardise sectors like hydroelectricity and tourism (Kelsey, 2018; Ngoma et al., 2019). Moreover, education, gender, and tenure status significantly influence forest dependency, with poorer and less educated households being more vulnerable to the consequences of forest degradation (Chishaleshale et al., 2024).

6.2.8 Integrated and Equitable Transition Pathways

The reviewed literature converges on a clear conclusion postulating that addressing Zambia's deforestation crisis requires more than technological fixes or conservation rhetoric. A truly sustainable energy transition must incorporate integrated policies that align forest conservation with rural development and clean energy access (Chishaleshale et al., 2024; UNODC, 2025). The Clean Energy - Deforestation Paradox serves as a cautionary tale for SSA's broader sustainability trajectory. Without targeted interventions that address both immediate livelihood needs and long-term ecological goals, the promise of solar PV and other clean technologies risks being undermined by the very environmental degradation they are intended to avert.

6.3 Theoretical Framework

To investigate the sustainability trade-offs of rural solar photovoltaic (PV) expansion in Zambia, this study adopts the Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM)(Chanda et al., 2025c, 2025b, 2025a, 2025e) (see Fig. 9). RUDSHAM provides an integrated, multi-theoretical lens to explore how rural communities navigate the competing imperatives of environmental conservation, energy access, and economic survival, especially within the paradox of unsustainably using forest resources to finance clean energy adoption.

RUDSHAM blends individual behavioural theories with structural and environmental insights, making it particularly suited for examining the Clean Energy - Deforestation Paradox. Central to the framework are three foundational theories: the Technology Acceptance Model (TAM) (Davis, 1989; Venkatesh and Davis, 2000), Diffusion of

Innovations (DOI) (Rogers, 2003a; Turner, 2007), and the Theory of Planned Behaviour (TPB) (Ajzen, 1991). Through TAM, it can be demonstrated how rural households weigh the perceived usefulness and affordability of solar PV systems, often prioritising short-term economic gains, such as lighting and phone charging, over long-term sustainability. Using DOI offers insight into how solar technologies spread within communities, highlighting the role of early adopters and local innovation networks. Meanwhile TPB, captures the behavioural intentions behind fuel choice and technology uptake, focusing on attitudes, social pressures, and perceived constraints. Crucially, RUDSHAM incorporates Social Learning Theory (SLT) (Bandura, 1977) to contextualise energy decisions within communal norms and peer influence. In rural Zambia, where resource scarcity and poverty dominate, energy choices are not made in isolation but are informed by the visible practices of neighbours and kin. For instance, a household that adopts a basic PV system using income from charcoal sales may inspire others to do the same, thus perpetuating deforestation while simultaneously advancing electrification.

Moreover, RUDSHAM is unique in embedding policy, economic, and environmental variables into its framework. This allows the framework to go beyond household decision making to assess broader governance and market structures that shape energy transitions. In the Zambian context, where institutional capacity is weak and energy financing mechanisms are scarce, RUDSHAM helps reveal how policy gaps intersect with grassroots behaviours, fuelling unintended consequences such as forest degradation to fund clean energy purchases.

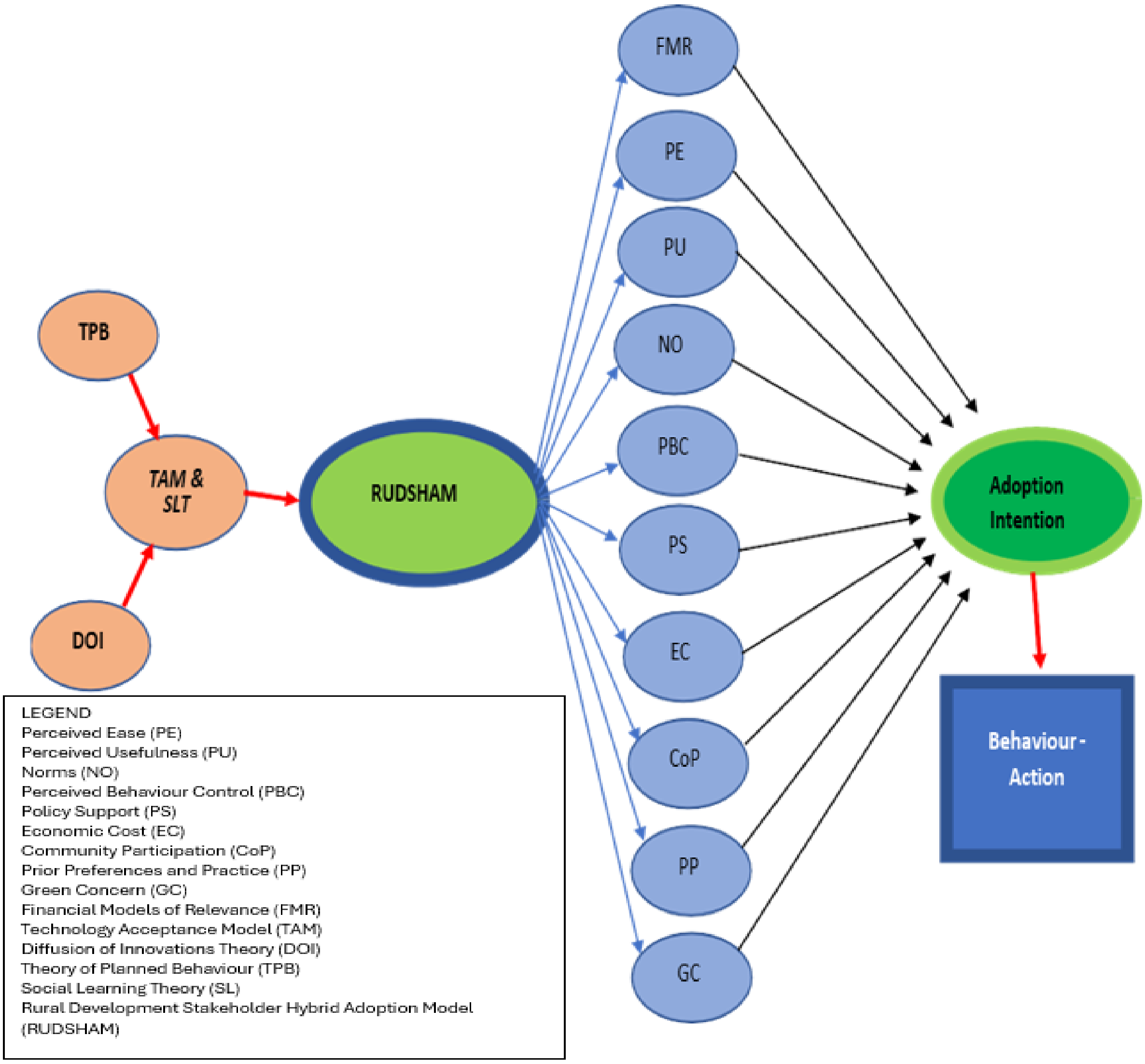

Figure 9: RUDSHAM Hybrid Adoption Model

By embedding household-level solar PV adoption within broader socio-economic and environmental systems, the RUDSHAM framework enables a comprehensive analysis of the Clean Energy - Deforestation Paradox. While solar technologies offer environmental gains, their uptake, when financed through forest exploitation, may inadvertently compromise sustainability goals. Applied to Zambia, RUDSHAM integrates technological, behavioural, and policy dimensions, offering valuable insights into rural energy transitions. This study employs a mixed methods approach, including in-depth interviews, focus groups, and observational data, complemented by carbon loss analysis based on remote sensing data. Based on this, the study estimates both carbon stock loss and foregone carbon sequestration linked to distinct categories of forest loss. This research contributes to a more nuanced understanding of rural energy transitions, equipping policymakers with actionable strategies to facilitate a just, sustainable, and economically viable energy transition in the Zambian and Sub-Saharan African contexts. For a detailed breakdown of RUDSHAM's attributes and applications refer to Appendices A and B. These appendices serve as the practical and analytical foundation of this study. Appendix A outlines the implementation logic through the RUDSHAM Policy Implementation Wheel, offering a sequential guide for policymakers and practitioners. Appendix B provides in-depth descriptions of each attribute, illustrating how they informed data collection, analysis, and interpretation within rural solar PV contexts in Zambia. Together, they bridge theory and application, enabling a comprehensive understanding of social, economic, and behavioural dimensions of energy transitions.

6.4 Research Methodology

This study employs a mixed methods approach grounded in the RUDSHAM framework (Chanda et al., 2025a, 2025b, 2025c), to examine the sustainability trade-offs of rural solar PV expansion in Zambia. The research investigates how rural households finance solar PV systems through both major and subtle forms of forest exploitation, focusing on the implications for environmental sustainability.

6.4.1 Study Design and Fieldwork Sites

Fieldwork was conducted over a 28-month period (October 2022 - February 2025) in four purposively selected rural districts (see Fig. 10): Mkushi Rural and Kapiri Rural (Central Province), Chongwe Rural (Lusaka Province), and Chingola Rural - Luano (Copperbelt Province). These regions were selected for their isolation, lack of grid electricity, and prevalence of charcoal production. A multi-stage, non-probability sampling strategy guided participant selection for focus group discussions (FGDs) and interviews, with charcoal burners, smallholder farmers, commercial farmers, and key stakeholders from the energy and policy sectors forming the primary respondent base.

6.4.2 Data Collection Methods

Primary data collection comprised 21 in-depth interviews with full-time charcoal burners, 40 interviews with smallholder farmers, 16 with commercial farmers, and 3 with stakeholders from solar companies and policy institutions. Ten FGDs were conducted across the sites, each with 7 - 12 participants. Three FGDs were exclusively for charcoal producers. Gender sensitive strategies, such as separate sessions for men and women, were employed to foster inclusive and balanced dialogue. Facilitators included local leaders and a research assistant fluent in English and several local languages (Bemba, Tonga, Soli, Lamba, and Nyanja), which enhanced participant engagement and data quality. Appendix C provides further details.

6.4.3 Data Analysis Framework

Qualitative data from interviews and FGDs were recorded, transcribed, and analysed using NVIVO 14 software. A systematic thematic analysis, structured by RUDSHAM, was conducted to explore linkages between perceived usefulness of solar PV, policy support, community influence, and the economic drivers behind forest exploitation. Colour coded nodes and NVIVO's advanced querying tools allowed for nuanced identification of behavioural patterns, trade-offs, and socio-environmental dynamics in the Clean Energy - Deforestation Paradox. A four week pilot in Luano refined the instruments, ensuring the validity and reliability of the tools.

6.4.4 Ethical Considerations and Data Security

Ethical research standards were upheld throughout, with ethical approval provided by the University of Reading's ethics committee prior to data collection. Participants gave informed consent prior to interviews and recordings (See Appendix J). All data, including transcripts, photographs, and videos, were securely stored on the University of Reading's OneDrive cloud server with restricted access. Tokens of appreciation and refreshments were provided in recognition of participants' contributions.

Figure 10: Map of Zambia (UN 2022)

6.4.5 Carbon Stock Analysis Using Remote Sensing Data

To quantify environmental impact, geospatial analysis was conducted using Hansen et al.'s (Hansen et al., 2013) global forest cover dataset (2001 - 2023), processed in Quantum Geographic Information System (QGIS 3.34). The dataset has a 30 metre (900m^2/pixel) spatial resolution, which enables precise measurement of forest loss in the four regions. A 10% canopy threshold was applied to classify forest cover, aligning with standard global forest definitions (FAO-FRA, 2025). Total forest loss areas were further categorised into three carbon relevant drivers: (i) forest fires, (ii) charcoal and fuelwood, and (iii) timber harvesting. Forest fire related losses were directly extracted from the Global Forest Loss Due to Fire dataset (Tyukavina et al., 2022). The remaining categories were estimated based on established national trends: charcoal and fuelwood are responsible for approximately 90% of forest loss, while timber harvesting contributes around 3% (Forest Trends, 2021; GFW, 2025; LCMS, 2022; USAID A2C, 2021; ZNCAF, 2023). Losses attributable to other minor drivers, such as bark stripping, honey harvesting, or mopane worm collection, were excluded from this analysis due to a lack of reliable quantitative data in the existing literature. This study calculates both immediate carbon emissions and the foregone carbon sequestration potential, depending on the end-use of forest biomass, whether it is combusted through forest fires, converted into fuel sources such as charcoal and firewood, or retained in long-lived wood products like sawn timber. Based on these assumptions, this study estimates both carbon stock loss and foregone carbon sequestration associated with each category of forest loss (see equations 5 - 8).Carbon stock loss (tCO_2) was calculated based on the loss of aboveground biomass (AGB), using the following equations:

- *Carbon Stock Loss (tC)=Forest Loss (ha) ×AGB × Emission Factor × Carbon Fraction*

(Equation 5)

- *Carbon Stock Loss (tCO_2) = Carbon Stock Loss (tC)×3.67*
  (Equation 6)

The emission factor varies by category: a combustion factor of 0.50 is applied for forest fire (IPCC, 2019); 1.00 is applied for charcoal and fuelwood, and 0.00 for timber harvesting, assuming that the biomass is retained in long-lived wood products. AGB is assumed to be 69.6 t/ha, representing the value for tropical dry forests over 20 years old (IPCC, 2006). A carbon fraction of 0.47 is applied to convert biomass to carbon content (IPCC, 2006). Belowground biomass (BGB) is excluded as it does not contribute to immediate emissions and is not combusted or removed during most forest clearance processes.

Future carbon sequestration loss (tCO_2 /year) was estimated as the annual amount of carbon that would have been sequestered by the forest if it had not been cleared, using the following equation:

- *Future Carbon Sequestration loss (tC/yr) = Forest Loss (ha) × AGB Growth Rate (t/ha/yr) ×Carbon Fraction*
  (Equation 7)

- *Future Carbon Sequestration loss (tCO_2 /yr) =Future Carbon Sequestration (tC/yr) ×3.67*

  (Equation 8)

This calculation was applied consistently across all three categories, assuming a growth rate of 1.6 t/ha/year (IPCC, 2019) and a carbon fraction of 0.47.

6.5 Findings Section

The findings reveal a complex relationship between solar photovoltaic (PV) adoption and deforestation in rural Zambia, where low-income households frequently rely on forest based activities to finance clean energy technologies. Charcoal production, forest clearing for agriculture, and unsustainable harvesting of non-timber forest products are common income generating practices that directly contribute to environmental degradation. While harmful to ecosystems, these practices serve as fallback income streams amid a lack of inclusive energy financing pathways. As such, deforestation is not merely an energy source issue but becomes a financing mechanism for accessing modern energy. This paradox illustrates the unintended ecological consequences embedded within grassroots clean energy transitions in Sub-Saharan Africa. Most households interviewed used small scale solar home systems (SHSs) ranging from 10W to 100W, primarily for basic lighting, phone charging, and powering radios (Chanda et al., 2025a). Many of these systems were acquired through Pay-As-You-Go (PAYG) models facilitated by mobile network operators and solar vendors, while a smaller proportion were purchased outright using lump-sum payments.

6.5.1 Charcoal Production and Forest Resource Depletion

The data in Table 16 suggest that charcoal production is widely perceived by participants as a major contributor to forest depletion in the surveyed area, with harvesters reportedly shifting to small, fruit, and medicinal trees due to dwindling availability of larger species. Economic necessity appears to override sustainable practices, with potential implications for woodland ecosystems.

Table 16: Participant Responses Related to Charcoal Production and Deforestation

a	*Participant*	*Illustrative Direct Quotation*
1	*Charcoal Burner FGD 2*	*"In the past, only mature, good trees that produced the best charcoal were used for charcoal production. But with the shrinkage of forests, we are now forced to use even small trees and sometimes fruit trees."*
2	*Charcoal Burner FGD 1*	*"Times are hard, and there is so much demand for charcoal with fewer right trees. Hence, we have been forced to start cutting even useful trees like fruit trees and medicinal trees."*
3	*Charcoal Burner FGD 1*	*"Some of the best trees used for charcoal burning are also host trees for mopane worms…"*
4	*Charcoal Burner FGD 2*	*"For a 25m³ kiln, we use a minimum of about 10 trees ranging from around 7 metres in height and above. For very big trees, it might take just a few to make a kiln, but they tend to be more expensive if you are buying them."*
5	*Charcoal Burner FGD 1*	*"The cost of buying about 10 trees for one kiln of 25m³ is around K500 ($20), and the cost of a single tree averages around K100 ($4), which is used for various purposes, including traditional timber processing."*

6.5.2 Forest Degradation and Local Experiences

The findings in Table 17 reflect a widespread perception of visible environmental degradation in the study areas, particularly in rural zones where deforestation is reported to be more pronounced than in better-managed commercial farming zones. Participants identified multiple actors such as farmers, timber processors, and charcoal burners, as contributors, though their views diverged on who holds primary responsibility.

Table 17: Forest Degradation and Local Observations

b	Participant	Illustrative Direct Quotation
1	Commercial Farmer Interview 3	*"I own some planes, and I have been flying between Lusaka and Mkushi, and gosh, when you look at how the number of trees has reduced since 1986 to now, it's a sad state of affairs."*
2	Charcoal Burner FGD 1	*"The people blame us for the lack of rain, but we are not the only ones cutting down trees. Those doing farming are sometimes even worse. And a lot of people cut trees for timber and other purposes too, so they cannot heap the entire blame on us, it's not fair."*
3	Commercial Farmer Interview 7	*"When you look at the villages and the areas where rural people live, all the trees are gone compared to the area on the side of the commercial farmers, which is well preserved. It's sad."*

6.5.3 Reforestation, Land Use, Resource Access

The evidence in Table 18 points to uneven reforestation efforts, with reported tree scarcity near settlements forcing individuals to travel longer distances for forest products. Participants noted that local leadership dynamics and perceived inequities in land governance may be contributing to ongoing unsustainable use of forest resources.

Table 18: Reforestation, Land Use, Resource Access

c	Participant	Illustrative Direct Quotation
1	Commercial Farmer Interview 9	*"We have planted about 3 hectares of gum trees and eucalyptus, which we allow our workers to use for firewood"*
2	Commercial Farmer Interview 1	*"Both charcoal and agriculture contribute to deforestation, but charcoal is worse."*
3	Charcoal Burner FGD 2	*"The nearby trees close to the villages and roads have been depleted. Hence, for someone to find good trees, they have to travel long distances…"*
4	Charcoal Burner FGD 1	*"Some chiefs and headmen are corrupt and are actually at the forefront of charcoal burning since they have huge traditional portions of land by virtue of their positions, which they use to make charcoal and cut trees."*

6.5.4 Beekeeping, Honey Harvesting and Forest Use

The testimonies in Table 19 indicate that while honey collection remains economically valuable, participants linked certain harvesting methods such as tree cutting and fire-setting to broader forest degradation. These accounts suggest tensions between livelihood practices and sustainability objectives in forest management.

Table 19: Beekeeping, Honey Harvesting and Forest Use

d	Participant	Illustrative Direct Quotation
1	CF Interview 10	*"Look at this big tree that has just been cut down...There was something in that tree he wanted, either the Mopani worms or the honey …"*
2	Chongwe Interview 12	*"I collect 'Ubuchi' (Honey) from different places like trees, anthills, or underground burrows…I use smoke to collect the honey from beehives. The problem these days is that there are very few trees."*
3	Mkushi Interview 3	*"…a 2.5ltr sells for $15 US (K300), and natural honey is always on high demand…it sustained me and helped me buy a good bicycle, household items and even pay back the solar lighting loan…"*
4	Kapiri Interview 13	*"When the beehive is in a tree… , I start a fire around or in the tree…If the beehive is in a difficult position…, I may cut off the branch or…the tree…"*
5	Kapiri FGD 1	*"Sometimes the honey collectors… cut down trees to access the honey. We have seen big trees that end up completely burnt or destroyed in the process… In other cases, they accidentally start forest fires…"*

6.5.5 Other Forest Product Extraction

The data in Table 20 raise concerns about the sustainability of harvesting practices related to products like Masuku fruits and Munkoyo roots. Participants observed that these resources, while critical to livelihoods, are being harvested in ways that may jeopardise species regeneration and forest diversity over time.

Table 20: Other Forest Product Extraction

e	Participant	Illustrative Direct Quotation
1	Chongwe Interview 2	"Masuku tree numbers are dwindling because some people use them for charcoal burning… and …cut down… during agricultural land clearing…"
2	Kapiri FGD 2	"We dig to get the roots of the munkoyo shrub, which ultimately dies…"
3	Kapiri FGD 2	"Due to excessive harvesting of munkoyo roots, loss of forest, and land clearing for agriculture, the munkoyo shrubs have reduced in number…"

6.5.6 Mopane Worm Harvesting

The findings in Table 21 indicate that the commercial value of mopane worms may be contributing to increased pressure on host trees such as Mutondo and Mpasa. Participant accounts suggest that the felling of these trees to access caterpillars could have broader ecological implications, including risks to long-term food security.

Table 21: Mopane Worm Harvesting

f	Participant	Illustrative Direct Quotation
1	CF Interview 14	"Well, people come to our farm and chop down trees to collect the caterpillars (Mopane worms) ...There's one particular variety called the Mutondo [Cordyla Africana] tree which got completely wiped out from my farm…"
2	CF Interview 10	"Look at this big tree that has just been cut down!... Obviously, there was something in that tree he wanted, either the Mopani worms or the honey…"
3	Mkushi Interview 2	"I sell the worms at $25 US (K500)/20ltr container…in a good season you can raise a lot of money…I did not struggle to buy uniforms for my children... necessities, nice phone, radio and the solar lighting…"
4	Mkushi Interview 1	"Mopane worm numbers have drastically reduced in the past decades because of overharvesting and cutting down of trees…"
5	Mkushi FGD 1	"But we don't know what the future holds because there has been overharvesting in recent decades due to increased demand. Mpasa [Julbernadia globiflora], Mutondo [Cordyla Africana] and Miombo [Brachystegia boehmii] trees are mainly the trees that host the caterpillars, and which have been cut down during Mopane worm collection…"

6.5.7 NTFPs and Biodiversity Depletion

Participant narratives in Table 22 suggest that non-timber forest products (NTFPs), including mushrooms and medicinal plants, are central to local diets and incomes. However, these products are reported to be declining in availability, potentially linked to land clearing and reduced tree cover in surrounding areas.

Table 22: NTFPs and Biodiversity Depletion

g	Participant	Illustrative Direct Quotation
1	CF Interview 9	"…many people come through my farm because we try to preserve the forest, which allows mushrooms to thrive. I don't stop them, but I warn them against cutting trees."
2	Mkushi FDG 2, Mkushi Interview 3	"Mushroom thrives well under trees and health forest, sadly the tree numbers have reduced… Land clearance for agricultural purposes is another contributing factor."
3	Kapiri FGD 2	"…we collect enough mushroom and other NTFPs for consumption and selling…many of us use part of income to pay back loans for solar lighting systems which the mobile companies give us..."
4	Kapiri Interview 21	"When I find animals that thrive in trees while hunting, and they run up a tree, I cut down the tree."
5	CF Interview 6	"…certain trees, fruits, roots, and other plants have medicinal properties that locals use…"

6.5.8 Forest Fires and Their Origins

The data in Table 23 point to rising concerns among participants about the frequency and impact of forest fires, which are often attributed to human activities such as hunting, charcoal production, and honey harvesting. These accounts suggest that such fires may pose risks to property, crops, and remaining forest resources.

Table 23: Forest Fires and their Origins

h	*Participant*	*Illustrative Direct Quotation*
1	*CF Interview 15*	*"One of the biggest dangers to crops, trees and property that we face is forest fires which we have to deal with almost on a yearly basis. They sometimes started by boys hunting small animals in grass, or by charcoal burners or by honey collectors and sometimes naturally. One time the fire almost reached the farm filling station… it's a real danger."*
2	*Kapiri FGD 3*	*"We guard against forest fires because we have thatched houses and for the sake of our crops and trees. Burning helps improve the soil but if not done properly it goes out of control. Sometimes its starts naturally or by kids in the bush or by our charcoal burners etc."*
3	*Kapiri FGD 1*	*"Sometimes the honey collectors… cut down trees to access the honey. We have seen big trees that end up completely burnt or destroyed in the process… In other cases, they accidentally start forest fires…"*

6.5.9 Agricultural Expansion and Fertiliser Use

Responses in Table 24 describe how declining soil fertility, attributed to repeated fertiliser use, has driven some respondents to clear new farmland. Unlike charcoal production, agricultural expansion was described as involving the removal of all vegetation, which may carry more extensive ecological consequences.

Table 24: Agricultural Expansion and Fertiliser Use

i	*Participant*	*Illustrative Direct Quotation*
1	*Charcoal Burner Interview 7*	*"Fertiliser has destroyed the soil to such an extent that it's almost impossible to get yield without fertiliser and treated seeds..."*
2	*Charcoal Burner FGD 1*	*"The introduction of fertiliser and total dependence on it has seen many portions of land quickly lose fertility due to chemical use, meaning that new farms need to be opened."*
3	*FGD Mkushi, Luano, Kapiri, Chongwe.*	*"Land clearing for agriculture is worse for the environment than agriculture because all trees including small trees are cut and burnt but charcoal burners only pick the mature trees and leave the small ones as they are not useful."*

6.5.10 Medicinal Tree Use and Knowledge

The findings in Table 25 illustrate that indigenous tree species continue to play a vital role in local health systems. However, participants expressed concern that these species are becoming increasingly scarce, which they linked to forest degradation and expanding human pressures on forest resources.

Table 25: Medicinal Tree Use and Knowledge

j	Participant	Illustrative Direct Quotation
1	*CF Interview 12*	*"I am aware of the traditional medicines used, especially by people who live far from clinics and town centres. However, I personally rely on conventional medicine."*
2	*Mkushi FGD 2*	*"… 'Chibangalume' [Zanha Africana] tree bark used to treat headaches and colds, 'Umunsokansoka' [Cassia abbreviate] used to treat stomach pains and malaria, guava leaves used to treat diarrhoea, and avocado roots used to boost blood levels, etc."*
3	*Charcoal Burner FGD 1*	*"We use both rubber ropes and ropes made from certain tree bark called "Inshishi" to tie our charcoal. The bark-made ropes are also very useful for making fences, binding firewood together, etc."*

4	*Charcoal Burner FGD 2.*	*"Though we produce charcoal, we rarely use it for cooking as it's meant for sale. All of us here depend on firewood… Charcoal is for the wealthy… laughs."*

6.5.11 Deforestation from Tree Multi-Use

The accounts in Table 26 highlight that certain tree species are reportedly used for multiple purposes such as fuel, food, medicine, and income generation, placing them under mounting pressure. This perceived overuse may be weakening forest resilience and accelerating localised deforestation.

Table 26: Deforestation from Tree Multi-Use

k	Participant	Illustrative Direct Quotation
1	*Mkushi FGD 1*	*"Mpasa [Julbernadia globiflora], Mutondo [Cordyla Africana] and Miombo [Brachystegia boehmii] trees are mainly the trees that host the caterpillars, and which have been cut down during Mopane worm collection…"*
2	*CF Interview 10*	*"Look at this big tree that has just been cut down...There was something in that tree he wanted, either the Mopani worms or the honey …"*
3	*CF Interview 11*	*"If I take you through this forest, you'll see some beautiful trees that have been cut..."*

6.5.12 Carbon Stock Loss and Future Sequestration Calculations

The results presented in Tables 27, 28, and 29 illustrate the estimated carbon stock loss and the foregone carbon sequestration potential resulting from forest degradation linked to fires, charcoal and fuelwood extraction, and timber harvesting across Zambia and the four study districts. Among these drivers, charcoal and fuelwood production dominate both carbon stock loss and foregone carbon sequestration. In the case of carbon stock loss, they are followed by forest fires, while timber harvesting causes no direct loss because the harvested carbon remains stored in timber products. By contrast, for foregone carbon sequestration, timber harvesting represents the next largest contribution, with forest fires having the smallest effect. Figure 11 further highlights both major and subtle drivers of deforestation, showing how social, economic, and environmental pressures collectively shape forest loss. Together, these findings demonstrate the continuing strain on forest resources and their significant implications for Zambia's carbon balance and broader climate mitigation efforts.

Table 27:Carbon Stock Loss and Future Sequestration Calculations - Forest Fire

Forest Fire										
Carbon Stock Loss	**Zambia**		**Chingola**		**Kapiri Mposhi**		**Mkushi**		**Chongwe**	
	2008~ 2015	2016~ 2023	2008~ 2015	2016~ 2023	2008~ 2015	2016~2023	2008~ 2015	2016~ 2023	2008~ 2015	2016~ 2023
Forest area loss due to Forest Fire (ha)	4,975.18	10,374.64	0.21	0.03	43.53	37.33	6.16	2.99	1.26	5.12
AGB (t/ha)	69.6	69.6	69.6	69.6	69.6	69.6	69.6	69.6	69.6	69.6
Emission Factor	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Carbon Fraction	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Carbon stock loss(tC)	81,374	169,687.60	3.44	0.53	711.91	610.56	100.79	48.90	20.58	83.77
Carbon stock loss(tCO_2)	298,642	622,753.49	12.64	1.94	2,612.70	2,240.74	369.90	179.46	75.53	307.45
Future Carbon Sequestration loss	**Zambia**		**Chingola**		**Kapiri Mposhi**		**Mkushi**		**Chongwe**	
	2008~ 2015	2016~2023	2008~ 2015	2016~ 2023	2008~ 2015	2016~ 2023	2008~2015	2016~ 2023	2008~ 2015	2016~ 2023
Forest area loss(ha)	4,975.18	10,374.64	0.21	0.03	43.53	37.33	6.16	2.99	1.26	5.12
AGB Growth Rate（t/ha/yr）	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Carbon Fraction of	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Future Carbon Sequestration Loss (tC/yr)	3,741.33	7,801.73	0.16	0.02	32.73	28.07	4.63	2.25	0.95	3.85
Future Carbon Sequestration Loss (tCO_2 /yr)	13,730.69	28,632.34	0.58	0.09	120.12	103.02	17.01	8.25	3.47	14.14

Table 28: Carbon Stock Loss and Future Sequestration Calculations - Charcoal and Fuelwood

Charcoal and Fuelwood										
Carbon Stock Loss	**Zambia**		**Chingola**		**Kapiri Mposhi**		**Mkushi**		**Chongwe**	
	2008~2015	2016~ 2023	2008~ 2015	2016~ 2023	2008~ 2015	2016~ 2023	2008~ 2015	2016~ 2023	2008~ 2015	2016~ 2023
Forest area loss (ha)	620,733	1,074,226	2,502	5,611	18,985	38,765	20,226	40,804	3,377	6,431
% of Forest Loss: Charcoal/Fuelwood	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
Forest Loss: Charcoal/Fuelwood (ha)	558,660	966,803	2,252	5,050	17,087	34,889	18,203	36,724	3,039	5,788
AGB (t/ha)	69.6	69.6	69.6	69.6	69.6	69.6	69.6	69.6	69.6	69.6
Emission Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Carbon Fraction of Aboveground Biomass	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Carbon stock loss(tC)	18,274,876	31,626,073	73,661	165,192	558,934	1,141,273	595,470	1,201,302	99,422	189,334
Carbon stock loss(tCO_2)	67,068,795	116,067,687	270,335	606,256	2,051,286	4,188,470	2,185,374	4,408,780	364,877	694,855
Future Carbon Sequestration loss	**Zambia**		**Chingola**		**Kapiri Mposhi**		**Mkushi**		**Chongwe**	
	2008~2015	2016~ 2023	2008~ 2015	2016~ 2023	2008~ 2015	2016~ 2023	2008~ 2015	2016~ 2023	2008~ 2015	2016~ 2023
Forest Loss: Charcoal/Fuelwood	558,660ha	966,803ha	2,252ha	5,050ha	17,087ha	34,889ha	18,203ha	36,724ha	3,039ha	5,788ha
AGB Growth Rate（t/ha/yr）	1.6t	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Carbon Fraction	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47

Future Carbon Sequestration Loss (tC/yr)	420,112	727,036	1,693.35	3,797.52	12,849.05	26,236.15	13,688.96	27,616.15	2,285.55	4,352.50
Future Carbon Sequestration Loss (tCO_2 /yr)	1,541,811	2,668,223	6,215	13,937	47,156	96,287	50,238	101,351	8,388	15,974

Table 29: Carbon Stock Loss and Future Sequestration Calculations - Timber Harvesting

Timber Harvesting										
Carbon Stock Loss	**Zambia**		**Chingola**		**Kapiri Mposhi**		**Mkushi**		**Chongwe**	
	2008~ 2015	2016~ 2023	2008~ 2015	2016～ 2023	2008~ 2015	2016~ 2023	2008~ 2015	2016~ 2023	2008~ 2015	2016~ 2023
Forest area loss (ha)	620,733	1,074,226	2,502	5,611	18,985	38,765	20,226	40,804	3,377	6,431
% of Forest Loss: Timber Harvesting	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
Forest area loss: Timber Harvesting(ha)	18,622	32,227	75	168	570	1,163	607	1,224	101	193
Emission Factor	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carbon Fraction	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Carbon stock loss(tC)	0	0	0	0	0	0	0	0	0	0
Carbon stock loss(tCO_2)	0	0	0	0	0	0	0	0	0	0
Future Carbon Sequestration loss	**Zambia**		**Chingola**		**Kapiri Mposhi**		**Mkushi**		**Chongwe**	
	2008~2015	2016~ 2023	2008~20 15	2016~ 2023	2008~2015	2016~ 2023	2008~2015	2016~2023	2008~20 15	2016~20 23
Forest area loss: Timber Harvesting (ha)	18,622	32,227	75	168	570	1,163	607	1,224	101	193
AGB Growth Rate（t/ha/yr ）	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Carbon Fraction	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Future Carbon Sequestration Loss (tC/yr)	14,003.74	24,234.54	56.45	126.58	428.30	874.54	456.30	920.54	76.19	145.08
Future Carbon Sequestration Loss (tCO_2 /yr)	51,393.71	88,940.76	207.15	464.56	1,571.87	3,209.56	1,674.62	3,378.38	279.60	532.46

6.5.13 Major and Minor (Subtle) Drivers of Deforestation

Figure 11 presents the major and minor drivers of deforestation as identified through interviews and focus group discussions across the study sites. The main drivers which include, charcoal production (largely driven by urban demand), timber extraction, firewood collection (for cooking and heating), and agricultural expansion, emerged as the dominant causes of forest loss, linked to increasing rural energy needs, expanding cultivation, and market pressures for charcoal in urban areas experiencing frequent power outages, high tariffs, and dependence on wood based fuels and products. In addition, several secondary but important factors were reported, including the use of firewood for funeral gatherings, uncontrolled forest fires, hunting, harvesting of medicinal plants and bark, honey collection, and the extraction of Mopani worms. Although these minor activities occur on a smaller scale, their combined and sustained impact contributes significantly to ongoing forest degradation. Together, these ten drivers indicate that deforestation in the study areas is influenced by a complex interplay of economic necessity, subsistence practices, and cultural traditions. There is, therefore, a need for integrated forest management strategies that address both direct and indirect human interactions with forest ecosystems.

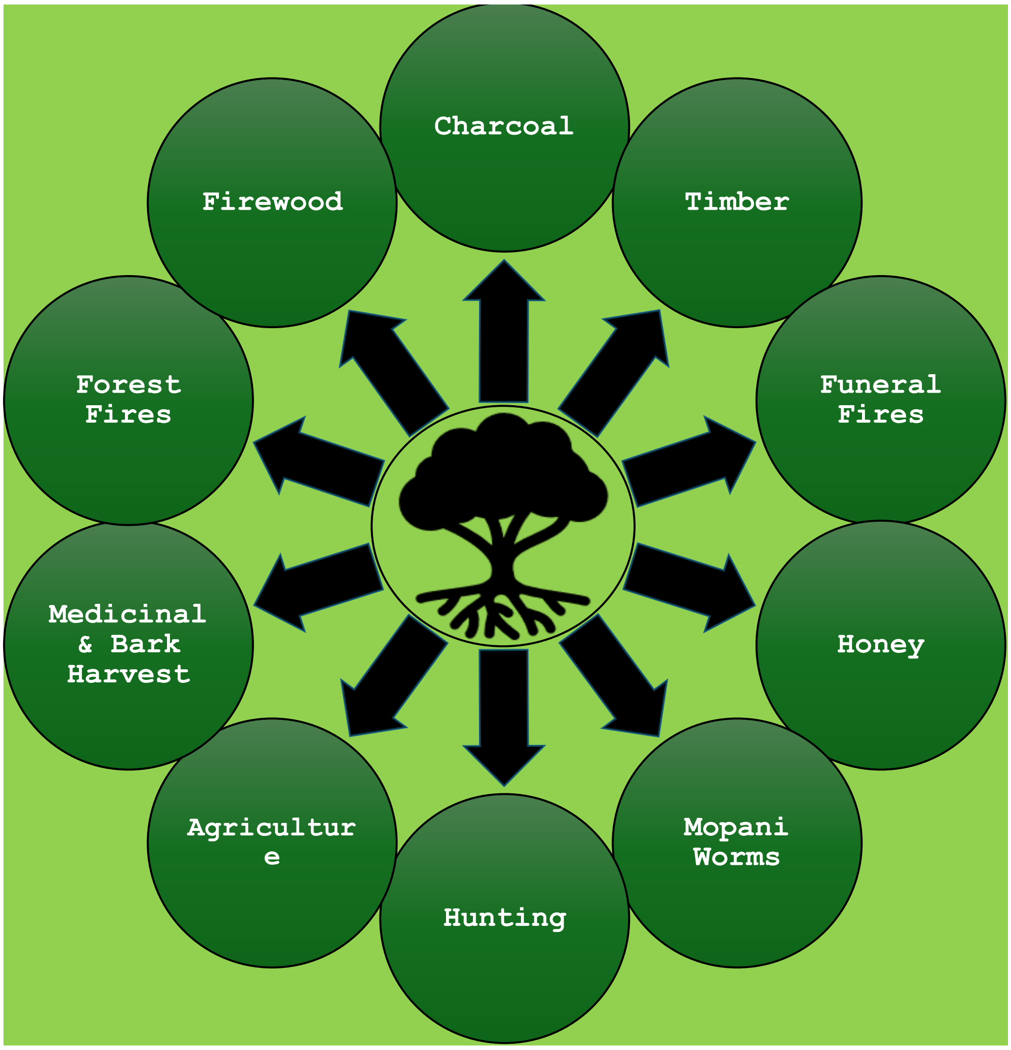

Figure 11: Major and Minor (Subtle) Drivers of Deforestation

6.6 Discussion

This study reveals a striking contradiction at the heart of Zambia’s rural energy transition: while solar PV technologies are promoted as instruments of environmental stewardship, their grassroots uptake is often seemingly financed through practices that contribute directly to ecological degradation. This phenomenon (the clean energy-deforestation paradox) suggests a complex feedback loop wherein clean energy aspirations intersect with unsustainable livelihood strategies, ultimately challenging prevailing assumptions about energy transitions in Sub-Saharan Africa (SSA).

At the core of this paradox lies the structural dependency on biomass energy and forest-derived incomes. As shown in the findings, many rural households appear to resort to charcoal production and non-timber forest product (NTFP) harvesting to generate income which is partly used to buy solar PV systems. This mirrors patterns highlighted by Gumbo et al. (Gumbo et al., 2013) and Kazungu et al. (Kazungu et al., 2020), who demonstrate that forest exploitation often serves as both a direct and indirect energy access mechanism. However, unlike traditional biomass use where firewood or charcoal is the end use fuel, in Zambia's case, biomass becomes a transactional intermediary and an economic bridge to modern energy access (ZamStats, 2022). This reveals a deeper structural vulnerability embedded in Zambia's decentralised energy model. As noted by Nygaard et al. (Nygaard et al., 2016), PAYG solar systems have enabled rural uptake, but the financial burden remains high relative to rural income levels. The absence of inclusive financing mechanisms such as micro credit, subsidies, or cooperative models, may force marginalised populations to monetise natural capital. Consequently, as Chanda et al. (Chanda et al., 2025b) argue, clean energy adoption without corresponding financial safeguards has the potential to exacerbate environmental injustice, whereby the costs of sustainability are offloaded onto ecologically vulnerable communities (Chishaleshale et al., 2024).

A salient pattern across the findings is the multi-functionality of forest resources. Tree species such as Mutondo, Mpasa, and Miombo simultaneously serve as hosts for mopane worms, sources of firewood, charcoal, food, and medicine. This multifunctionality appears to create cumulative pressure on biodiversity hotspots and echoes concerns raised by Guedje et al. (Guedje et al., 2016) regarding the unsustainable harvesting of multi-use species. The Jevons Paradox becomes increasingly relevant in this context. Even as solar PV ostensibly reduces reliance on biomass for lighting, the economic incentive to harvest forests for income to finance such technologies may undermine ecological gains, as supported by Goulart et al. (Goulart et al., 2023) and Tazebew et al. (Tazebew et al., 2023). Furthermore, the role of ecosystem degradation in reinforcing poverty cycles is particularly pronounced. Soil degradation from excessive fertiliser use, documented in both the findings and by Tyagi et al. (Tyagi et al., 2022), compels continuous agricultural expansion into forested areas, further escalating deforestation. This dynamic illustrates a negative feedback loop where reduced soil fertility leads to deforestation, which in turn diminishes ecosystem services, such as water retention and pollination, thereby reducing agricultural productivity and pushing households further toward environmentally harmful income-generating activities (Raj et al., 2022). In support, Mubanga & Bwalya (Mubanga and Bwalya, 2020) and Verma (Verma, 2015) have noted that such trade-offs are frequently rooted in short-term adaptation strategies that prioritise survival over sustainability.

A critical contribution of this study is the foregrounding of under-acknowledged practices which include honey harvesting, bark stripping, medicinal plant extraction, and mopane worm collection, as possible significant contributors to forest degradation. These are often excluded from policy assessments and conventional land-use metrics. This finding aligns with Chungu et al. (Chungu et al., 2007), who emphasise the ecological significance of ‘invisible drivers’ in forest decline. More importantly, the commodification of these practices, particularly when linked to the financing of solar technologies, complicates simplistic binaries of “clean” versus “unclean” energy (Chanda et al., 2025c; Kasaro et al., 2019). This calls for an integrated understanding of sustainability that accounts not only for carbon displacement but also for the socio-ecological conditions under which clean technologies are acquired. As Mohammed (Mohammed, 2020) and UN-REDD+ (UN-REDD+, 2024) contend, sustainability must be evaluated holistically, considering lifecycle impacts and local trade-offs. A solar lantern displacing kerosene may reduce indoor air pollution and carbon emissions, but if it is financed through the felling of medicinal trees or the ignition of forest fires, its net environmental benefit might arguably be reduced or become questionable (Walling and Vaneeckhaute, 2021).

Governance failures appear to further compound these contradictions. Zambia’s forest and energy policies remain siloed, with limited cross-sectoral coordination (Guo et al., 2023; Ratnasingam et al., 2014). The findings illustrate how weak enforcement, local leadership complicity, and inequitable access to reforestation programmes exacerbate unsustainable forest use. This institutional fragmentation prevents the alignment of rural energy access goals with forest conservation imperatives. REDD+ and similar mechanisms have struggled to integrate energy needs into conservation frameworks, often neglecting the economic realities of rural households (Manda and Mukanda, 2023). As a result, communities are left navigating an unsustainable middle ground and are caught between conservationist imperatives and the pressing need for energy and income (Forest Trends, 2021). The political ecology of forest access also emerges as a key consideration. As seen in the participant testimonies, rural communities often face inequitable land and resource governance structures. Chiefs and headmen, by virtue of traditional authority, are sometimes reported to exploit forests for personal gain, undermining collective stewardship. This aligns with Moreira-Dantas & Söder (Moreira-Dantas and Söder, 2022), who identify corruption and elite capture as persistent threats to community-led conservation. These dynamics also skew energy equity, as wealthier households and actors, such as commercial farmers, are often better positioned to adopt solar technologies without resorting to forest exploitation (Chanda et al., 2025b).

Ecologically, the degradation of Zambia’s Miombo woodlands and associated biodiversity presents potential cascading consequences. Reduced forest cover may jeopardise not only flora and fauna but also microclimatic stability and agricultural viability (Ngoma et al., 2024; Raj et al., 2022). The decline of NTFPs such as mushrooms, honey, and mopane worms signals an erosion of dietary diversity and rural livelihoods. These losses are not just ecological but profoundly socio-economic, threatening food security, cultural practices, and resilience in the face of climate stressors (Anyango et al., 2018; Carpio-Domínguez, 2024). At the same time, there are glimmers of adaptive potential. The study notes that some commercial farmers have initiated small-scale reforestation efforts and provide controlled access to firewood. While limited in scope, such examples point to the possibility of hybrid energy-environment arrangements, where local actors serve as intermediaries in supporting both clean energy and sustainable resource use. However, these efforts must be scaled and institutionalised within a coherent policy framework (Chishaleshale et al., 2024).

This discussion suggests that sustainability is not a function of technological substitution alone. It is also a function of social equity, governance architecture, and ecological interdependence. Without addressing the structural conditions under which solar PV systems are financed and adopted, the clean energy transition runs the risk of inadvertently accelerating the very environmental degradation it seeks to resolve. As SSA continues to scale up decentralised energy systems, the Zambian case offers a cautionary lesson: energy justice must be pursued alongside, not in isolation from, ecological justice.

6.6.1 Carbon and Sequestration Loss Analysis

Carbon stock loss in Zambia (see Tables (27) to (29)) exhibited significant variation based on the underlying drivers of forest loss (see Fig. 11). Across both periods (2008 - 2015 and 2016 - 2023) (see Fig. (12) to (31)), charcoal and fuelwood emerged as the dominant contributors to carbon emissions in all regions. Nationally, emissions from charcoal-related forest degradation increased markedly from 67,068,795 tCO_2 in 2008 - 2015 to 116,067,687 tCO_2 in 2016 - 2023. These values were estimated by applying a 90% attribution factor to total forest loss, reflecting national-level trends that identify charcoal and fuelwood as the dominant drivers of deforestation in Zambia. By contrast, emissions from forest fires remained comparatively lower, rising from 298,642 tCO_2 to 622,753 tCO_2 over the same timeframe. Timber harvesting, by its nature, did not contribute to immediate carbon stock loss, as much of the biomass remains stored in long lived wood products. Patterns in future carbon sequestration loss mirrored those of immediate emissions. Zambia's estimated annual loss in carbon sequestration capacity from charcoal and fuelwood rose from 1,541,811 tCO_2 /year (2008 - 2015) to 2,668,223 tCO_2 /year (2016 - 2023). Timber harvesting accounted for lower annual losses of 51,394 tCO_2 /year and 88,941 tCO_2 /year, respectively. Losses from forest fires remained modest, at 13,731 tCO_2 /year and 28,632 tCO_2 /year across the two periods.

At the district level, Mkushi experienced the most severe impact, recording 4,408,780 tCO_2 in emissions from charcoal and fuelwood between 2016 and 2023, with an associated sequestration loss of 101,351 tCO_2 /year. Kapiri Mposhi and Chongwe followed, while Chingola exhibited the lowest values, with 606,256 tCO_2 in emissions and 13,937 tCO_2 /year in sequestration loss. Although emissions from forest fires increased slightly across districts, they remained consistently lower than other sources throughout the study period. Deforestation is also partly driven by NTFP extraction, including bark harvesting, mopane worm collection, and honey production. However, the trees lost are also eventually largely used for charcoal production contributing to localised deforestation and carbon loss. However, due to a lack of spatially disaggregated data, these drivers could not be separately quantified.

Legend: Tree Cover (Green) Tree Loss (Red)

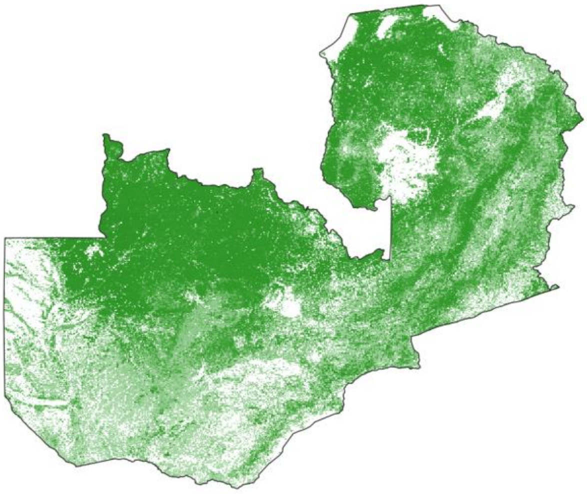

Figure 12 Zambia Tree Cover (2008)

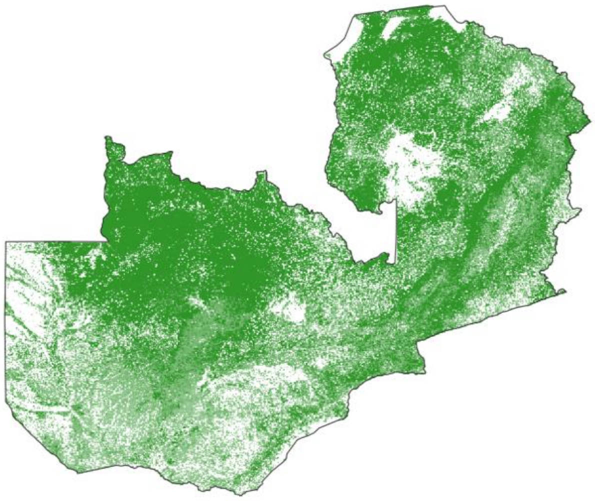

Figure 13 Zambia Tree Cover (2023)

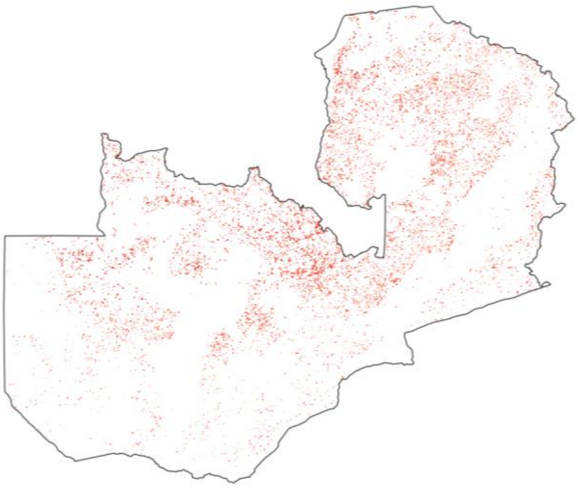

Figure 14 Zambia Tree Loss (2008-2023)

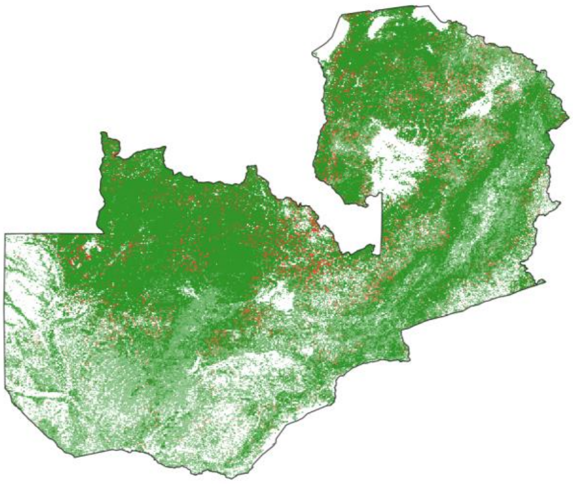

Figure 15 Zambia Tree Cover (2023) + Tree Loss (2008-2023)

Legend: Tree Cover (Green) Tree Loss (Red)

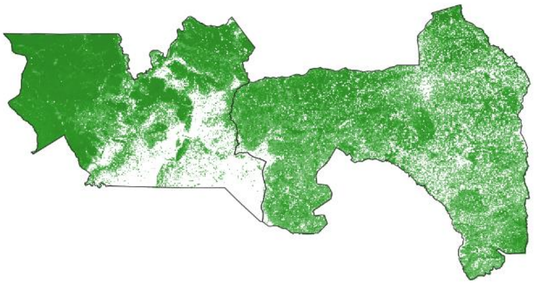

Figure 16 Kapiri Mposhi Tree Cover (2008)

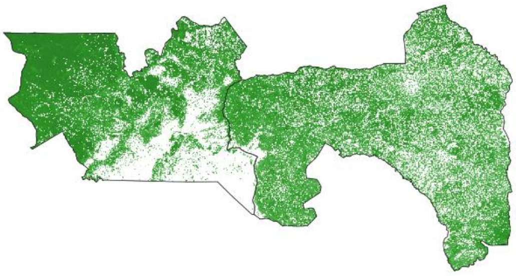

Figure 17 Kapiri Mposhi Tree Cover (2023)

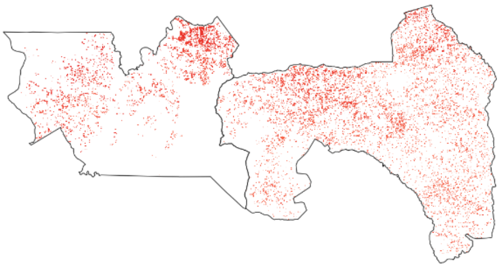

Figure 18 Kapiri Mposhi Tree Loss (2008-2023)

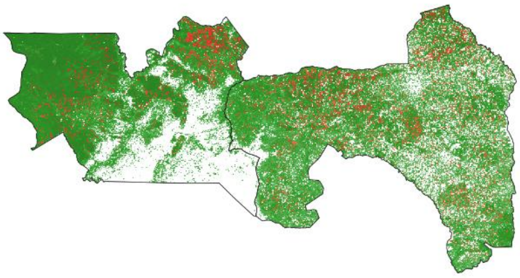

Figure 19 Kapiri Mposhi Tree Cover (2023) + Tree Loss (2008-2023)

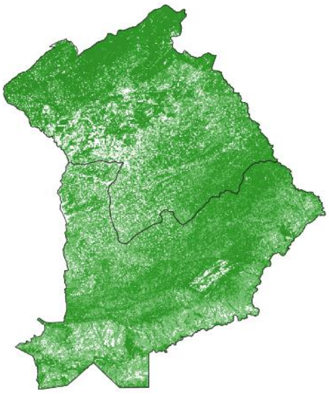

Figure 20 Mkushi Tree Cover (2008)

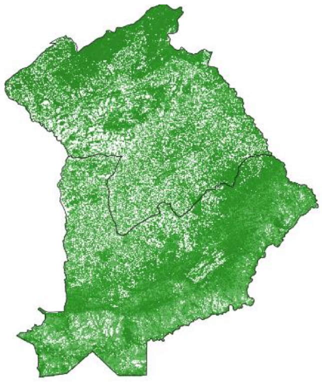

Figure 21 Mkushi Tree Cover (2023)

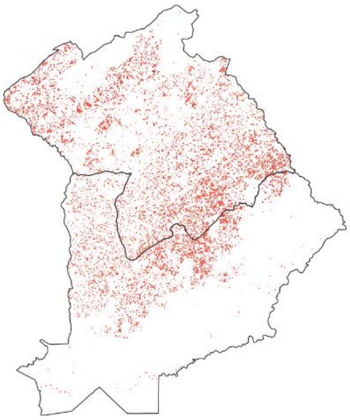

Figure 22 Mkushi Tree Loss (2008-2023)

Figure 23 Mkushi Tree Cover (2023) + Tree Loss (2008-2023)

Legend: Tree Cover (Green) **Tree Loss (Red)**

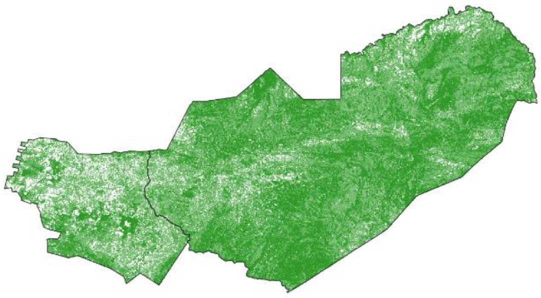

Figure 24 Chongwe Tree Cover (2008)

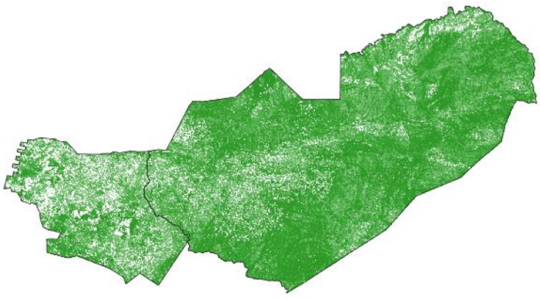

Figure 25 Chongwe Tree Cover (2023)

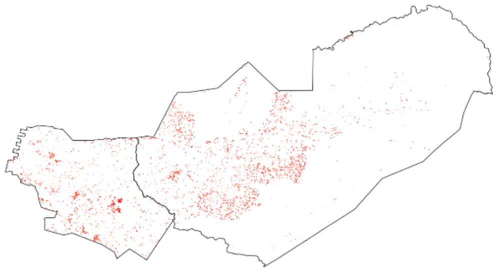

Figure 26 Chongwe Tree Loss (2008-2023)

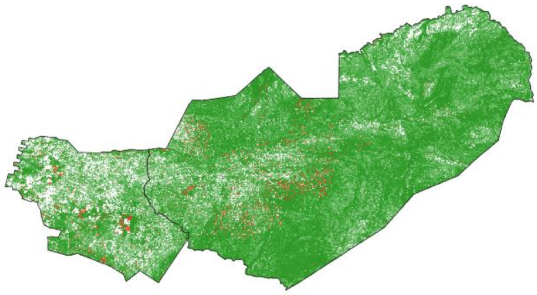

Figure 27 Chongwe Tree Cover (2023) + Tree Loss (2008-2023)

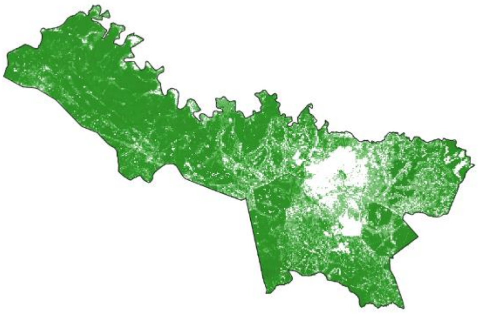

Figure 28 Chingola Tree Cover (2008)

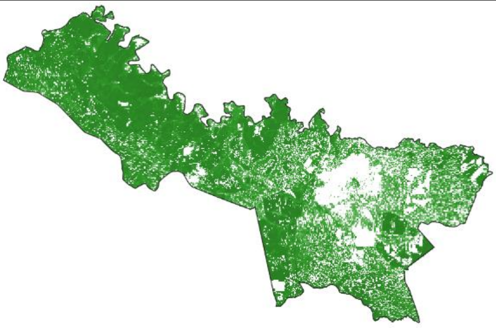

Figure 29 Chingola Tree Cover (2023)

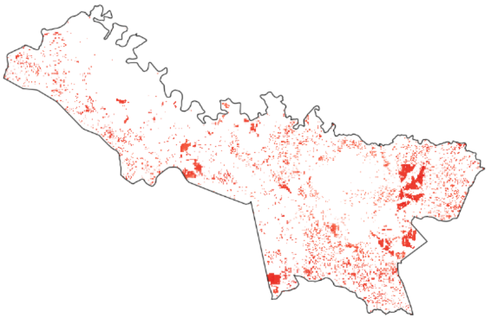

Figure 30 Chingola Tree Loss (2008-2023)

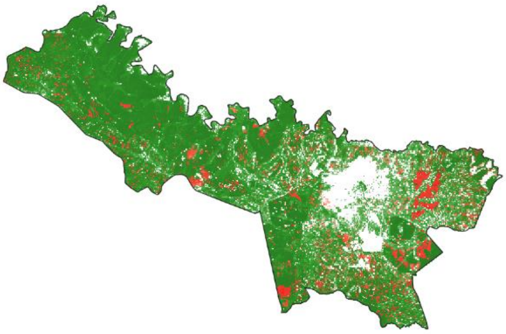

Figure 31 Chingola Tree Cover (2023) + Tree Loss (2008-2023)

6.7 Recommendations

A number of policy recommendations are made below that reflect the challenges posed by the deforestation-clean energy paradox. Rather than treating clean energy expansion and environmental preservation as separate pursuits, policymakers must embrace a holistic, systems based approach. This entails aligning incentives, restructuring financing mechanisms to reduce dependency on forest incomes, and strengthening institutional capacities across the forestry, energy, and agriculture sectors.

6.7.1 Integrate Forestry and Energy Policies

A cohesive policy approach is required to bridge the gap between clean energy promotion and forest conservation. The Ministry of Energy and the Ministry of Green Economy and Environment must collaboratively develop integrated policies that consider how rural solar PV adoption is financed and the potential forest costs of such transitions. Synergies between energy access targets and forest preservation efforts can be achieved through joint planning and inter-ministerial coordination.

6.7.2 Implement Forest-Sensitive Solar Subsidies

To reduce reliance on income from environmentally harmful practices, solar PV financing mechanisms must be designed to accommodate the economic realities of forest dependent households. The Ministry of Finance, in partnership with the Rural Electrification Authority, should pilot targeted subsidies and zero-interest solar loan schemes for vulnerable groups. International aid organisations such as the United Nations Development Programme (UNDP) and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) can provide technical support and financing for these programmes.

6.7.3 Scale Up Sustainable Livelihood Alternatives

The promotion of alternative income-generating activities that do not rely on forest degradation is vital. The Ministry of Community Development and Social Services, alongside development partners like the World Food Programme (WFP) and SNV Netherlands Development Organisation, should invest in training and support for value chains such as agroforestry, apiculture, mushroom cultivation, and eco-tourism. These options can provide income without further depleting natural resources.

6.7.4 Strengthen Local Forest Law Enforcement

Empowering community-based forest management structures is key to sustainable forest use. The Forestry Department should work closely with traditional authorities to enforce tree harvesting regulations, monitor deforestation hotspots, and promote reforestation. Local resource user groups can be equipped with tools, training, and legal backing to act as stewards of their natural environment.

6.7.5 Integrate Environmental Education into Outreach

Awareness-raising campaigns on solar energy should incorporate forest conservation messages. The Ministry of Education, working with civil society organisations and media outlets, can develop culturally relevant materials that highlight the long-term risks of financing solar systems through deforestation. Including environmental ethics in school curricula can cultivate a new generation of forest-conscious energy consumers.

6.8 Conclusion

6.8.1 Key Findings and Contributions

This study uncovers a rarely addressed dilemma in rural energy transitions called "The Clean Energy-Deforestation Paradox", where the adoption of clean technologies like solar PV is financed through ecologically damaging activities such as charcoal burning, bark harvesting, mopane worm collection, and land clearing etc which drive deforestation. While solar PV provides clean lighting solutions, its household level acquisition strategies in rural areas sometimes involves unsustainable income sources that exacerbate deforestation and biodiversity loss.

One of the most significant contributions of the research is its empirical demonstration of how micro level economic behaviours link energy aspirations to environmental degradation. These links have been largely overlooked in mainstream clean energy and forestry debates. The study highlights not only the major drivers of deforestation but also subtle, under researched ones such as bark removal for ropemaking, tree cutting for; honey collection, mopane worm gathering and hunting access, and multi-purpose exploitation of the same tree species across different sectors. Methodologically, the study is grounded in the Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM), which provides a holistic framework to examine sustainability trade-offs. RUDSHAM enables the integration of household-level socio-economic dynamics with ecological outcomes, allowing a deeper understanding of how rural actors navigate energy transitions under constrained conditions.

This research advances knowledge by problematising the assumption that clean energy uptake is universally positive. It presents an alternative lens through which to evaluate sustainability, one that considers not just outcomes, but the means through which those outcomes are achieved. By focusing on the financing behaviours behind solar PV adoption, the study contributes new insight into the environmental cost of clean energy in low-income, forest-dependent settings.

6.8.2 Future Research Directions

While this study offers a comprehensive qualitative exploration of the Clean Energy - Deforestation Paradox, future research could expand its scope through spatial modelling and life-cycle assessments. Quantitative studies tracking forest degradation over time in high-solar adoption areas would offer valuable insights into land-use change dynamics. Additionally, there is a need to examine the gendered dimensions of forest-product-based solar financing, as women and girls often bear disproportionate burdens in both energy provision and environmental labour.

6.8.3 Study Limitations

One limitation of the study is its 28 month data collection window, which, while extensive, may not fully capture the seasonal fluctuations in deforestation-related activities or long-term changes in solar financing trends. A longer study period would enable more robust tracking of deforestation patterns and solar adoption behaviours over time. Expanding the sampling of income-generating activities across a broader geographic area could offer additional perspectives and help enrich the understanding of patterns that may also be relevant in other parts of Zambia and the wider Sub-Saharan African region. As with many qualitative studies, the findings are grounded in participant narratives and observational accounts, which, while rich in contextual depth, do not offer precise quantification of ecological impacts such as bark stripping, mopane worm harvesting, or medicinal tree extraction. Future research would benefit from mixed-methods or ecological field studies to empirically measure the extent and ecological consequences of these practices, thereby validating or refining the patterns observed in this study.

6.8.4 Summary

The study stresses the urgent need to reconcile rural energy access goals with environmental sustainability objectives. Addressing this paradox requires not just improved solar distribution but a fundamental rethinking of how clean energy transitions are financed and governed in forest-dependent communities. By surfacing hidden costs and overlooked drivers of deforestation, this research offers a critical step toward more inclusive, integrated, and ecologically sound development planning in Zambia and beyond.

Chapter 7: Community-Led Solar Energy Technology Adoption in Rural Zambia: The Role of Observational Learning and Neighbour Influence. (Article 3)

Status: Published - Energy Research & Social Science Journal

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Summary: This article investigates how community-led processes, particularly observational learning and peer influence, affect the uptake of solar photovoltaic (PV) systems in rural Zambia. It challenges the effectiveness of top-down technology dissemination strategies and highlights the pivotal role of local networks, social visibility, and neighbourly interaction in shaping adoption behaviours.

Abstract: Key findings reveal that visual exposure to functioning PV systems and consultations with peers significantly enhance both willingness to pay and user confidence. Households are more likely to adopt solar technologies after witnessing tangible benefits among neighbours, such as improved lighting or reduced reliance on kerosene. Individual benefits, once demonstrated, often cascade into broader community level participation, thereby reinforcing social norms around energy transition. Importantly, donor-driven interventions that fail to consider these community dynamics risk underperformance or project abandonment.

Recommendations: Recommendations call for the formal incorporation of "solar champions" (community members who can demonstrate, educate, and influence uptake) within policy frameworks. Energy programmes should prioritise grassroots communication channels and invest in peer-based training models to maximise community ownership and long-term sustainability.

Overall contribution: This article addresses Thesis Objective 2, contributing vital insights into community-driven adoption pathways and the behavioural fabric of rural solar engagement. It complements the broader thesis by providing a nuanced account of how rural Zambians actively shape, adapt, and circulate energy innovations in ways that often exceed formal planning mechanisms.

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Keywords: Solar PV Adoption, Peer Influence, Observational Learning, Community Participation, Rural Energy Access, Zambia

7.1 Introduction

The global energy landscape is witnessing a significant shift driven by renewable energy (RE) technologies, particularly solar photovoltaic (PV) and wind, which collectively account for 70% of global power capacity expansion (De Freitas, 2022). Rooftop PV systems are gaining widespread acceptance among populations (Schulte et al., 2022). The increasing popularity of solar communities, attributed to the falling prices of PV panels and enhanced PV efficiency, demonstrates the potential for PV panels to become a primary energy generation element in local energy contexts worldwide (Lazdins et al., 2021). In emerging economies, renewable energy technologies, particularly solar PV, are recognised as essential components in sustainable energy development, offering promising solutions to address energy poverty and achieve long-term sustainable energy goals (Chidembo et al., 2022; Komatsu et al., 2011).

Energy poverty in the rural African context refers to the lack of access to modern energy services such as electricity and clean cooking facilities. This condition is characterised by the reliance on traditional biomass (e.g. wood, charcoal, dung) and kerosene for lighting and cooking, which are inefficient and harmful to health and the environment (Nduka, 2021). Despite global initiatives, energy poverty remains a pressing issue, with over 573 million people in Africa and 840 million globally lacking access to electricity, and over 2.7 billion lacking access to clean cooking energy, primarily in developing countries (Antwi and Ley, 2021). The identification of solar PV technology as the largest available renewable energy source highlights its potential to alleviate energy poverty and drive socio-economic development, particularly in regions with limited energy access (Alipour et al., 2021). While the rapid growth in global energy demand and concerns about dwindling fossil fuel reserves and climate change have prompted policy interventions to promote renewable energy adoption, challenges persist, especially in developing countries (Elmustapha et al., 2018).

In Zambia, despite an average solar insolation level of 5.5 kWh/m2/day and 3000 hours of sunshine per year, only 3.23% (123.13MW) of its installed generation capacity is solar based, predominantly utilised for basic energy services such as lighting and mobile phone (also referred to as cell phones in other parts of the world) charging (ERB Report, 2023). Presently, 64% to 84% of the Zambian populace lacks access to electricity, a fundamental prerequisite for socio-economic advancement and poverty mitigation (Baye et al., 2021). Rural electrification rates are strikingly low, with less than 6% of rural dwellers having access to electricity, leaving over 94% of rural inhabitants in darkness (Kaoma and Gheewala, 2021). Zambia's energy landscape is further strained by an inadequate national grid exacerbated by reliance on hydroelectric power susceptible to climatic fluctuations. Climate-induced droughts have diminished hydroelectric output, precipitating frequent power rationing episodes lasting up to eight hours daily (ERB Report, 2023). Consequently, the country grapples with a substantial electricity deficit of 1,000 MW amidst a growing demand of 3,812.07 megawatts (Bayliss and Pollen, 2021; Dario, 2020; ERB Report, 2023), culminating in adverse economic ramifications such as reduced productivity, job losses, and diminished tax revenues. These energy shortages intensify developmental challenges within and across various sectors including healthcare, education, food security, and poverty alleviation (Feleke et al., 2023).

In response to the existing energy challenges, the Zambian government has outlined a diversification plan of energy sources, particularly towards off-grid and renewable energy, as a cornerstone of its 8th National Development Plan (2022-2026) aimed at achieving universal, clean, abundant, and affordable energy access (MOE, 2019). Notwithstanding governmental efforts, only 6% of the rural population has gained electricity access, exposing the inadequacy of current strategies (ERB Report, 2023). Challenges persist in expanding energy access to rural communities, worsened by limited government budgets and insufficient community engagement. Extant literature shows that, compared with diesel-powered electricity generation systems, solar photovoltaic systems are more affordable to no less than 36% of the unelectrified populations in East Asia, South Asia, and sub-Saharan Africa (Szabó et al., 2021). While the cost of Solar PV has decreased in recent years, energy service provision through RE remains capital-intensive, necessitating substantial upfront investments beyond the capacity of public budgets (Khan et al., 2021). In the context of energy applications, this means that seeing neighbours or community members successfully using solar PV can significantly increase the likelihood of others adopting similar systems. This effect is particularly relevant in rural areas, where traditional energy infrastructure is limited, and renewable energy can provide critical services. Recent research clearly demonstrates that effective community engagement, public awareness, and visual exposure to renewable technologies can enhance adoption rates (Axon, 2020; Chekol et al., 2023; Coy et al., 2022). These elements are crucial for overcoming barriers such as limited financing and technical challenges, promoting sustainable energy access, and supporting socio-economic development in underserved regions. Consequently, there is a growing interest among scholars, practitioners, and policymakers in understanding factors conducive to renewable energy adoption in rural communities and the role of community engagement in effective energy project management (Hoicka et al., 2021; Moner-Girona et al., 2018; Mugisha et al., 2021).

However, there is a notable dearth of studies investigating the specific challenges and mismatches between available Solar PV products and rural community needs, particularly in Africa (Bauwens et al., 2022; Brunet et al., 2018). In Zambia, the adoption of solar energy is hindered by numerous barriers, including the lack of sustainable financing and technical viability of Solar PV mini grids (Kapole et al., 2023). Following the failure of Mpanta's 60 kW solar mini-grid in northern Zambia, additional deployments, including Magodi (48 kW), Katamanda (52 kW), Chitandika (28 kW), Muhanya (24 kW), and Chibwika (32 kW), are now also facing critical sustainability issues (Kapole et al., 2023; Muhoza and Johnson, 2018). Although these projects hold potential to improve rural electrification, they encounter significant obstacles to long-term viability. Financial sustainability is a primary issue, as the tariffs necessary to meet capital and operational expenses are often unaffordable for low-income rural residents. Technical challenges also undermine success, with mini-grids frequently suffering from improper sizing, leading to either over/under capacity, thus affecting reliability and efficiency (Kapole et al., 2023).

Operational deficiencies intensify these sustainability challenges. Many mini-grids are managed by community or government bodies without adequate technical expertise, leading to inconsistent maintenance and shortened operational lifespans (Kapole et al., 2023; Stritzke and Jain, 2021). Further, viewing these systems as "donative" rather than commercial ventures limits community engagement and utilization. Misaligned subsidy structures that fail to accommodate stakeholder needs have only worsened these issues, undermining the grids' potential impact (Kapole et al., 2023; Muhoza and Johnson, 2018; Stritzke and Jain, 2021). Despite global advocacy for renewable energy adoption, Zambia faces unique challenges hindering widespread solar energy use. Specifically, issues with financing and the technical feasibility of solar PV mini grids present significant obstacles (Chaurey et al., 2012; Feleke et al., 2023; Kapole et al., 2023; Kuno et al., 2023; Sovacool, 2013). Addressing these challenges requires focused research and strategic interventions tailored to Zambia. Research from Zambia identifies several factors influencing intentions towards solar energy adoption.

Against this backdrop, this study seeks to address critical gaps in understanding solar energy adoption in rural Zambia. Specifically, we investigate the influence of social learning on successful technology adoption models in the rural Zambia context, as well as the relationship between exposure to solar technology and adoption intention within three rural communities. Parallel case studies (examining mobile phones, solar phone chargers, solar torches and piped water) from these communities are then presented to contrast perspectives of PV and its adoption with instructive approaches to introducing new technologies into rural communities. By exploring these dimensions, our research aims to contribute to the development of informed policies and interventions designed to promote sustainable energy access and foster socio-economic development in Zambia and similar contexts.

7.2 Literature Review

The intricate relationship between individual perceptions, socioeconomic conditions, and policy support plays a pivotal role in driving renewable energy adoption globally. Studies from developing countries globally highlight significant socioeconomic barriers, such as high installation costs and inadequate government financial support (Irfan et al., 2021; Qureshi et al., 2017; Shang et al., 2018). In Sub-Saharan Africa (SSA), including Ethiopia and Kenya, similar challenges persist despite policy interventions, emphasizing the need for affordability and effective policy implementation (Mekonnen et al., 2023; Opiyo, 2019). For example, in Malawi, consumers' aspirations for upgraded appliances indicate evolving energy needs, whereas in Rwanda, the use of home solar PV systems for income generation remains limited, pointing to untapped potential (Kizilcec and Parikh, 2020). Research on solar PV adoption in Zambia stresses the importance of context-specific factors. In Zambia, attitudes toward solar solutions, perceived benefits, and trust in the technology are significant drivers of adoption, alongside government incentives and social norms (Qureshi et al., 2017; Zulu et al., 2022). Comparatively, in South Africa, individual preferences and social identity are crucial (Chidembo et al., 2024; Elmustapha et al., 2018; Irfan et al., 2021). In Uganda, energy needs for business operations have less influence on adoption intentions, reflecting diverse adoption dynamics influenced by regional socioeconomic factors (Nabaweesi et al., 2024).

The perceived benefits and affordability of renewable energy adoption present a complex landscape in Sub-Saharan Africa (SSA). Holistic approaches that address technical, financial, and socio-economic factors are necessary for equitable energy access and sustainable development (Aker and Jack, 2021; Barrie and Cruickshank, 2017; Chidembo et al., 2022; Kapole et al., 2023; Opiyo, 2019; Stritzke and Jain, 2021). The dynamic nature of rural energy needs and the importance of understanding socio-economic benefits are emphasised. Challenges like technical inadequacies, poorly structured tariff charges, and market constraints pose obstacles to the sustainability of renewable energy initiatives, highlighting the need for innovative and integrated policy frameworks (Amuzu-Sefordzi et al., 2018; Durga et al., 2024; Kapole et al., 2023; Mekonnen et al., 2023). Education and public perception significantly impact the adoption of solar energy technologies in rural Africa. Improving awareness through education about the benefits of clean energy sources is essential for facilitating adoption (Ahmar et al., 2022; Wassie and Ahlgren, 2023). The narrative underscores the urgent need for renewable energy solutions to address prevalent energy access challenges in developing regions (Chidembo et al., 2024).

Social dynamics, including individual decision-making processes, social norms, peer influence, and information dissemination, are critical in solar photovoltaic (PV) adoption. Financial capabilities, attitudes towards green technologies, social norms, and peer behaviours significantly shape adoption behaviours (Brugger and Henry, 2019; Ngonda et al., 2023). Effective information dissemination and leveraging social capital are pivotal in promoting solar energy adoption, although strategies must be context-specific (Brugger and Henry, 2019; Korcaj et al., 2015; Ngonda et al., 2023; Parkins et al., 2018; Wolske et al., 2020). The role of social influence mechanisms in driving renewable energy adoption is increasingly recognised globally. Peer effects, observational learning, and word-of-mouth communication are crucial in shaping adoption behaviours. Non-price incentives, such as information provision and peer comparisons, effectively accelerate renewable energy technology adoption (Conway et al., 2019; Wolske et al., 2020). While empirical evidence from various countries showcases the effectiveness of social influence mechanisms, the Zambian situation is one of persistent energy poverty and limited clean energy access, necessitating further research on peer-based interventions (Masikati et al., 2021).

The literature highlights the significant role of peer effects in driving renewable energy adoption across diverse regions. Peer networks influence adoption behaviours, shape beliefs, and facilitate information dissemination. Social norms and community engagement are crucial for widespread adoption (Gillingham and Bollinger, 2021). However, the nature of peer influence varies, with studies from Zambia emphasizing the role of community leaders in alleviating fears and promoting acceptance of renewable energy technologies (Masikati et al., 2021). Leveraging social mechanisms for promoting sustainable energy adoption focuses on different aspects and contexts. Social learning and peer interactions significantly influence renewable energy adoption at the household level, as seen in Rwanda (Chang et al., 2021). Social interactions and peer networks directly influence household decision-making, reinforcing the importance of community dynamics (Wolske et al., 2020).

The adoption of solar energy in rural Zambia faces significant challenges due to the prevalence of counterfeit (fake products or fake labels) products, which negatively impact social dynamics and adoption behaviours. In October 2024, the Zambian government raised concerns over the surge of counterfeit solar products flooding the domestic market, emphasizing the potential risks to the country's solar adoption efforts (Ministry of Small and Medium Enterprise Development (Minister), 2024). Literature supports this concern, showing that counterfeit solar products are prevalent across Sub-Saharan Africa, especially in developing countries where regulatory measures often fall short of effective quality control (Dagnachew et al., 2020; Munro et al., 2023a; Samarakoon et al., 2021; Wassie and Adaramola, 2021). These substandard products erode consumer trust in solar technology and lead to higher long-term costs, as users frequently face premature replacement needs due to product failure. Counterfeit solar panels have become widespread due to economic constraints, regulatory weaknesses, and low consumer awareness, creating barriers to genuine solar technology adoption (Kapole et al., 2023; Munro et al., 2023a; Samarakoon et al., 2021). These issues collectively weaken community trust in solar technologies, which is a crucial component of social influence and peer-led adoption in rural communities (Dagnachew et al., 2020; Wassie and Adaramola, 2021). Economic barriers are a major driver of this trend. High poverty levels in rural Zambia restrict access to legitimate solar products, leading many consumers to purchase cheaper, counterfeit alternatives (Kapole et al., 2023; Mfune and Boon, 2008). This trend undermines social influence, as the adoption of unreliable products can cause dissatisfaction, reducing the likelihood that early adopters will positively influence their neighbours' adoption intentions.

Weak regulatory frameworks further exacerbate the problem, as inadequate enforcement allows counterfeit products to proliferate unchecked. This not only affects consumer confidence but also deters legitimate investors from entering the market, limiting the availability of quality solar options in rural areas (Kharas, 2007; Munro et al., 2023a; Samarakoon et al., 2021). A lack of community trust, compounded by substandard product performance, hampers positive social learning about solar benefits, thereby reducing adoption potential (Zulu et al., 2021). While social influence is typically a powerful factor in promoting solar energy adoption, the presence of counterfeit products generates negative social learning effects. To improve adoption rates and community acceptance, Zambia's solar energy market requires targeted regulatory reforms, heightened consumer awareness, and more robust quality controls (Utoh Imo-Obong et al., 2024).

Community-based interventions and understanding of socio-cultural contexts are crucial for promoting renewable energy adoption. Studies from West Africa, Sierra Leone, and Zambia emphasise the importance of community engagement for successful renewable energy initiatives. Leveraging trusted community networks, peer consultations, and community-led outreach initiatives effectively accelerate adoption. Addressing socio-cultural, geographic, and market dimensions with custom-made interventions tailored to local contexts and stakeholder perspectives is vital for shaping energy adoption behaviours (Elmustapha et al., 2018; Gillingham and Bollinger, 2021; Kapole et al., 2023; Liu and Bah, 2021; Muhoza and Johnson, 2018; Narjabadifam et al., 2023; Stritzke and Jain, 2021). Ward Development Committees (WDC) were introduced to enhance community participation in decision making. WDCs in Zambia are central to fostering community ownership and participation in local development. The National Decentralisation Policy (revised 2013) and the Constitution of Zambia (Amendment) Act No. 2 of 2016 establish a legal framework that supports devolved governance and promotes citizen engagement (GRZ MLGRD, 2021). Through section 36 of the Local Government Act No. 2 of 2019, WDCs formalise community participation by serving as conduits between local authorities and residents, coordinating community-centred development programmes, and leveraging socio-economic opportunities (GRZ MLGRD, 2021). Despite their importance, WDCs face significant operational challenges. Poor communication with local authorities, limited understanding of their broader functions beyond Constituency Development Fund (CDF) management, and undue political interference hinder their effectiveness. Additionally, the absence of financial incentives demotivates members, who often rely on personal resources to fulfil their roles (GRZ-LGA, 2023). A study in Chibombo district found that the operationalisation of most WDCs was poor, with issues such as financial irregularities, political affiliation, and weak adherence to governance guidelines limiting their functionality (Siachisa et al., 2023).

Research on solar energy adoption in rural areas consistently emphasises the powerful role of social influence, particularly through social learning, peer interactions, and communication channels. Social learning, involving both observation and active communication, significantly shapes adoption decisions in various rural contexts. For instance, studies in rural China show that social networks enhance adoption intentions through active discussions, although passive visual observation has a limited effect on its own (Liu et al., 2023). In Burkina Faso, household characteristics and the economic activities of communities also modulate adoption decisions, underscoring that social influence is closely intertwined with local economic conditions (Tinta et al., 2023). These findings highlight social learning as a crucial yet context-specific driver of solar PV adoption.

Peer influence further bolsters adoption, especially when early adopters become visible examples in their communities. In rural Kenya, the adoption rate of solar lanterns reached 96%, with families reporting a 14.7% reduction in annual expenses, reflecting how social and economic benefits reinforce adoption (Tong et al., 2015). Peer visibility, as observed in Kendu Bay, Kenya, leads to higher adoption rates as new installations inspire further uptake through word-of-mouth recommendations (Nixon Opiyo, 2019). Additionally, in large-scale interventions leveraging peer interactions, each municipality in the U.S. added 37 installations on average, demonstrating a substantial social learning effect and highlighting the economic advantages associated with adoption (Gillingham and Bollinger, 2021).

The efficacy of social influence also depends on communication from trusted community figures. Active communication from respected leaders has shown to increase adoption intentions by considerably reinforcing subjective norms around solar PV systems, as observed in China (Liu et al., 2023). Economic considerations, including perceived installation costs and the promise of long-term savings, are crucial to adoption, and geographic factors like sunlight access further impact decisions (Kelvin K. Kishara et al., 2024). Studies have found that structured informational campaigns, such as ambassador-led initiatives, increase installations by 37 units per community on average (Gillingham and Bollinger, 2021), with a critical mass threshold of 12.5%–15% optimizing community-wide adoption rates (Nixon Opiyo, 2019). Together, these studies reveal that social influence, if leveraged effectively, can notably drive the adoption of solar PV technology in rural settings across diverse socio-economic contexts.

Social influence has played a pivotal role in the successful adoption of renewable energy technologies across various regions. Observational learning and peer effects have been instrumental in encouraging the uptake of solar PV systems, particularly when individuals witness their neighbours or community members benefiting from these technologies. For instance, in Malawi, the aspiration for upgraded appliances has driven solar adoption, while in Rwanda, community engagement has fostered the spread of solar home systems. In Zambia, trusted community leaders have been key in alleviating fears and promoting acceptance of renewable technologies. These successes show the importance of leveraging social networks and peer interactions to enhance renewable energy adoption.

The primary message from the literature stresses the significance of social dynamics, community involvement and stakeholder engagement in promoting renewable energy adoption. Despite variations in research contexts and approaches, the emphasis on individual benefits, user-friendly technologies, community ownership, and addressing psychological barriers remains consistent. Holistic approaches, long-term development investments, and ethical research practices are essential for sustainable energy transitions. Enhancing knowledge dissemination and community consultation can facilitate broader adoption of renewable technologies, contributing to sustainable poverty alleviation and community empowerment. Despite the growing body of evidence on the importance of social influence and community engagement in renewable energy adoption, there remains limited empirical understanding of how these dynamics operate within the specific environmental, institutional, and livelihood contexts of rural Zambia. This study is therefore necessary to generate context grounded evidence on the governance, informal practices, and livelihood interactions shaping solar PV adoption and management, thereby addressing critical gaps in both policy design and academic literature.

7.3 Theoretical Framework

The current study sets out and utilises the new Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM) (see Fig. 32) to help explain the degree to which social learning is observed in solar PV adoption. RUDSHAM integrates three main theoretical models to understand the factors influencing the adoption of renewable energy technologies in rural areas. It combines the Technology Acceptance Model (TAM), Diffusion of Innovations Theory, and Theory of Planned Behaviour (TPB) to focus on internal factors affecting adoption willingness. TAM highlights performance expectancy, effort expectancy, social influence, and facilitating conditions as key drivers of technology adoption (Ajzen, 1991; Davis, 1989; Rogers, 2003a; Venkatesh and Davis, 2000). Diffusion of Innovations Theory explains the stages and factors influencing the spread of new technologies over time (Rogers, 2003a). TPB suggests that behavioural intentions are shaped by attitudes, subjective norms, and perceived behavioural control (Ajzen, 1991). Additionally, RUDSHAM incorporates Social Learning Theory, which emphasises the role of observation and imitation in shaping attitudes and adoption decisions (Bandura, 1977). Social dynamics, such as peer effects and active communication within social networks, significantly influence individuals' decisions to adopt renewable energy technologies. The social learning concepts that shape individual behaviours and societal norms within communities can be divided into social influence, peer influence, neighbour influence, community influence, and social dynamics. Social learning involves acquiring knowledge, behaviours, and attitudes through observing and interacting with others in the social environment (Antwi and Ley, 2021; Nixon Opiyo, 2019). It reflects the broader cultural and societal context within which individuals are embedded and highlights how community level factors shape, inform and influence individual behaviours and attitudes. Social dynamics, on the other hand, refer to the patterns, processes, and changes in social interactions and relationships within a given social system over time (Kizilcec and Parikh, 2020; Zulu et al., 2022). This provides a model for understanding the complexity and confluence of different social forces.

By combining internal factors from TAM, Diffusion of Innovations Theory, and TPB with external influences from Social Learning Theory and peer effects, RUDSHAM offers a comprehensive understanding of the multifaceted factors driving renewable energy adoption in rural developing areas. This holistic approach recognises the complex
interplay between individual beliefs, social influences, and community dynamics in shaping adoption behaviours. The framework provides valuable insights for policymakers, researchers, and practitioners aiming to promote sustainable energy transitions. RUDSHAM's alignment with a mixed-methods research approach, including in-depth interviews, focus groups and observations, ensures a thorough

examination of solar PV adoption in rural Zambia. This integration of theoretical and methodological rigour offers a robust foundation for investigating the complex factors impacting solar PV adoption, facilitating the development of effective strategies for sustainable energy development.

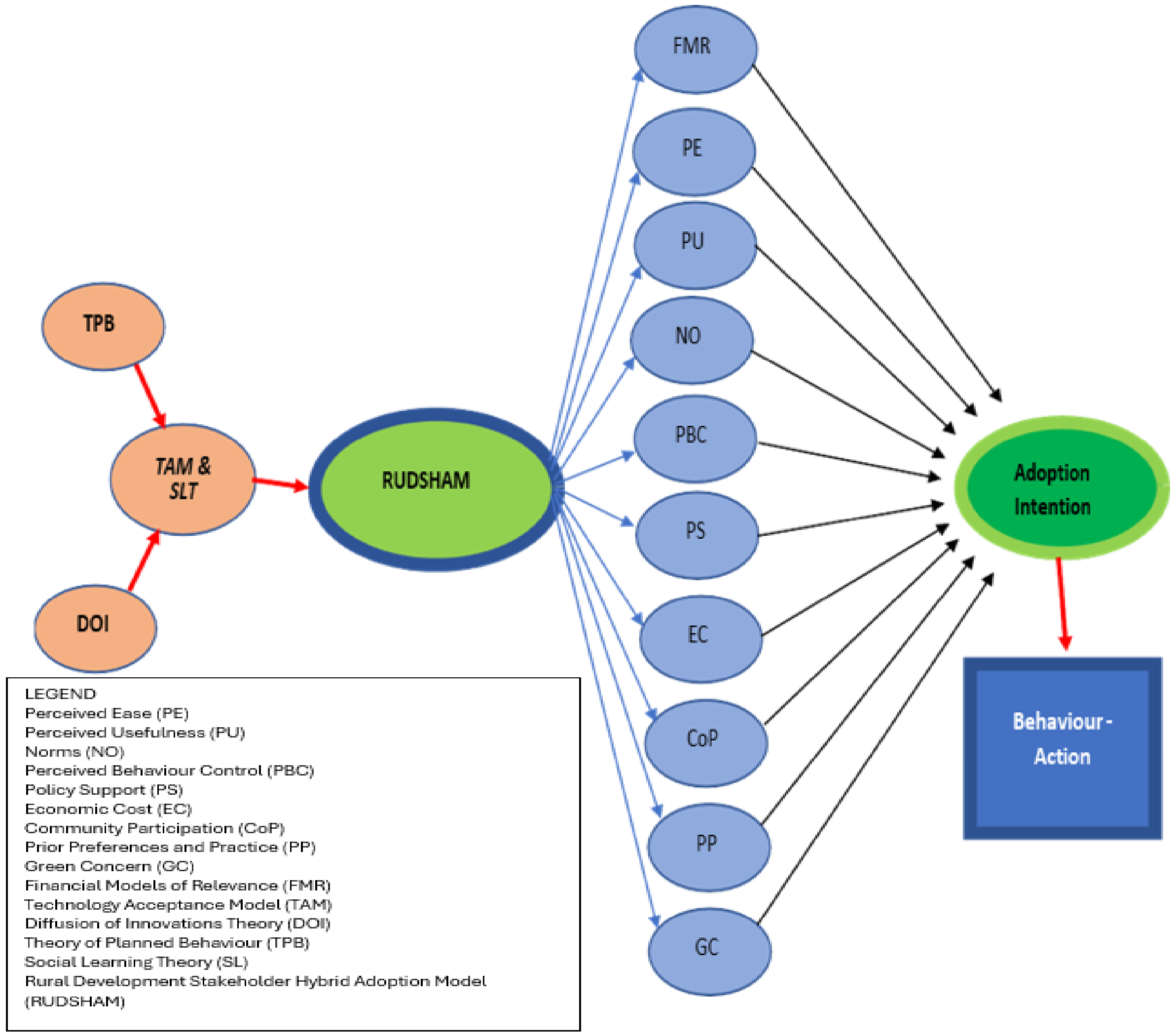

Figure 32: RUDSHAM Hybrid Adoption Model

7.3.1 Hybrid Framework (RUDSHAM) Explained

RUDSHAM provides a comprehensive framework to understand how social learning, social influence, community influence, and observational learning contribute to the adoption of solar PV in rural areas of Zambia. Below is a description of how each attribute of the RUDSHAM framework highlights these influences. The rate of innovation is influenced by several key attributes with social influence embedded as follows:

7.3.1.1 Perceived Ease (PE)

- Definition: Encompasses the ease of installation, use, maintenance, and access to experts for support.

- Social Learning/Influence: Observing others successfully install and maintain solar PV systems can ease concerns about complexity. Peer demonstrations and shared experiences lower perceived barriers, enhancing community confidence in adopting the technology. Research shows that perceived ease of use significantly influences technology adoption (Venkatesh and Davis, 2000).

7.3.1.2. Perceived Usefulness (PU)

- Definition: Factors include the technology's dependability, reliability, energy security, improvement over existing power sources, and productive use.
- Social Learning/Influence: Seeing the tangible benefits and improvements in the quality of life for early adopters can convince others of the utility of solar PV. Word of mouth and visual evidence of usefulness can be powerful motivators. The Technology Acceptance Model emphasises the importance of perceived usefulness in adoption decisions (Davis, 1989).

7.3.1.3. Norms (NO)

- Definition: Compatibility with social norms, household norms, social acceptability, and the influence of people's opinions and experiences.
- Social Learning/Influence: Social norms and peer influence play crucial roles. If solar PV is seen as socially acceptable and beneficial within the community, others are more likely to adopt it. Studies highlight the impact of social norms and peer pressure on environmental behaviours (Nolan et al., 2008).

7.3.1.4. Perceived Behaviour Control (PBC)

- Definition: The availability of return warranties, choice in configuration, guarantees, and the freedom and ability to choose to buy.
- Social Learning/Influence: Observing others' ability to control their solar PV usage and experience with warranties and guarantees can empower individuals to feel capable of managing the technology themselves. Ajzen's Theory of Planned Behaviour emphasises the role of perceived behavioural control in intention formation (Ajzen, 1991).

7.3.1.5. Policy Support (PS)

- Definition: Includes incentives, subsidies, government support, alignment with UNSDGs, support from solar PV suppliers, and effective communication.
- Social Learning/Influence: When communities observe successful policy supported initiatives, it reinforces the perceived legitimacy and safety of adopting solar PV. Government endorsements and subsidies can catalyze adoption through observed successes (Rogers, 2003a; Turner, 2007).

7.3.1.6. Economic Cost (EC)

- Definition: The price of solar PV systems and its impact on the decision to buy and overall energy expenditure.
- Social Learning/Influence: Learning about the economic benefits and long-term savings from peers who have adopted solar PV can mitigate cost concerns. Cost-benefit analyses shared within the community can promote adoption (Rai and Beck, 2015).

7.3.1.7. Community Participation (CoP)

- Definition: The extent of community ownership and involvement in designing, financing, and maintaining solar PV systems, as well as supplier engagement.
- Social Learning/Influence: High levels of community participation enhance collective learning and support structures, making adoption more likely. Community driven projects often succeed due to shared responsibility and mutual support (Hoffman et al., 2013; Walker and Devine-Wright, 2008).

7.3.1.8. Prior Preferences and Practice (PP)

- Definition: Current energy practices, preferences, key uses of energy, reasons for these preferences, and expectations.
- Social Learning/Influence: Observing peers transition from traditional energy sources to solar PV can shift preferences and practices, demonstrating viability and efficiency in the local context. Prior successful adoptions serve as a blueprint for others (Miller and Buys, 2008).

7.3.1.9 Green Concern (GC)

- Definition: Environmental concern and awareness of the impact at individual, household, and community levels.
- Social Learning/Influence: Seeing peers adopt solar PV for environmental reasons can heighten awareness and concern, encouraging others to follow suit. Environmental motivations often spread through social networks (Barr et al., 2010).

7.3.1.10 Financial Models of Relevance (FMR)

- Definition: Comparison of current finance practices with other relevant solar PV financial models globally and their applicability in the developing world context.
- Social Learning/Influence: Exposure to successful financial models and practices in similar contexts can influence local adoption by demonstrating financial viability. Observational learning of how financing can be managed effectively is crucial (Budzianowski et al., 2018; Chaurey et al., 2012; Shakeel et al., 2024).

7.3.2 RUDSHAM Methodological Application

The data collected aims to inform an understanding of social influence on solar PV adoption in rural Zambia by examining various aspects of community dynamics and individual perceptions. Through in-depth interviews and focus group discussions, the researchers explored perceived ease of use, perceived usefulness, social norms, and economic factors. By analysing these dimensions, the study revealed how observing peers, learning from community leaders, and understanding financial models and policy supports, informs and impacts upon individuals' decisions. This comprehensive approach highlights the role of social learning and peer influence in facilitating the acceptance and uptake of solar PV systems, providing insights for targeted interventions.

A methodology based on the ten attributes of the Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM) theory provided a detailed understanding of social influence on solar PV uptake in rural Zambia. Each attribute of the RUDSHAM theory contributed to revealing the social dynamics and factors affecting solar PV adoption.

7.3.2.1 Perceived Ease (PE)

Researchers collected data on the ease of installation, use, and maintenance of solar PV systems. By analysing responses from community members, they understood how user-friendly the technology was perceived to be and identified any barriers related to technological complexity that impacted adoption.

7.3.2.2 Perceived Usefulness (PU)

The research team assessed the perceived benefits of solar PV systems, such as reliability and energy security, by gathering community feedback. This helped them understand how the practical advantages of solar PV influenced community acceptance and trust in the technology.

7.3.2.3 Norms (NO)

By examining social and household norms, as well as the opinions and experiences of influential community members, researchers uncovered the significant role of social learning and peer influence. This analysis identified key opinion leaders who had the potential to promote solar PV adoption within their communities.

7.3.2.4 Perceived Behaviour Control (PBC)

Data on perceptions of control over the purchase and usage of solar PV systems, including the availability of warranties and configuration options, were gathered. This provided insights into how perceived autonomy and control affected decision-making processes regarding solar PV adoption.

7.3.2.5 Policy Support (PS)

Researchers evaluated the impact of government incentives, subsidies, and supplier support on solar PV adoption. This examination illustrated how external facilitation and effective communication of policies influenced community adoption rates.

7.3.2.6 Economic Cost (EC)

By analysing the economic cost of solar PV systems and its impact on household budgets, the research team understood how financial considerations played a crucial role in the decision to adopt solar PV technology.

7.3.2.7 Community Participation (CoP)

The level of community involvement in the design, financing, and maintenance of solar PV systems was assessed. This highlighted the importance of collective action and ownership in sustaining the adoption of solar PV technology.

7.3.2.8 Prior Preferences and Practice (PP)

Researchers investigated existing energy practices, preferences, and key uses of energy within the community. Understanding these factors provided a baseline against which the potential shift to solar PV could be measured.

7.3.2.9 Green Concern (GC)

Data on environmental concern and awareness at the individual, household, and community levels were collected. This helped researchers gauge the extent to which environmental motivations influenced the decision to adopt solar PV.

7.3.2.10 Financial Models of Relevance (FMR)

The research team compared current finance practices with other relevant solar PV financial models globally. This comparison highlighted the applicability and potential impact of different financial approaches on solar PV adoption in rural Zambia. Each attribute of the RUDSHAM framework emphasises different aspects of social learning, social influence, community influence, and observational learning. Together, they provide a holistic view of how these social dynamics facilitate the adoption of solar PV in rural Zambia, illustrating the importance of community involvement, perceived ease and usefulness, social norms, economic considerations, and supportive policies in driving sustainable technology adoption.

7.4 Research Methodology

By integrating data from the ten attributes set out in the previous section of the study, the RUDSHAM based methodology offered a comprehensive understanding of how social norms, perceived benefits, economic considerations, policy frameworks, and community involvement collectively influence the adoption of solar PV systems in rural Zambia. This approach enabled stakeholders to design targeted interventions that leveraged social influence to promote sustainable energy solutions.

The research was conducted over 6 months (October 2022 to March 2023) across 3 remote rural areas in Zambia: Mkushi Rural (Central Province), Kapiri Rural (Central Province), and Chongwe Rural (Lusaka Province) (see Fig. 33). These locations were strategically chosen for their relative isolation and lack of access to the national power grid. A 4-week pre-testing pilot study was conducted with 5 participants in Luano village (Chingola Rural, Copperbelt Province) to ensure the validity and reliability of the research instruments. One research assistant, fluent in English and several local languages (Bemba, Tonga, Soli, Lamba, and Nyanja), facilitated data collection. The primary investigator is also fluent in English and has a working knowledge of Bemba, Nyanja and Lamba.

The data collection involved in-depth interviews, ranging in duration from 30 minutes to 60 minutes, with 39 rural farmers, 16 commercial farmers, and 3 key stakeholders from solar energy companies and government policymakers. Additionally, 7 focus group discussions (FGDs), each comprising 8 participants from the selected rural areas (3 from Kapiri, 2 from Mkushi and 2 from Chongwe), were conducted to capture a range of opinions and views from the communities. To address gender sensitivity and dominance issues in FGDs, sessions were facilitated by village 'headmen' or councillors, taking advantage of their trusted positions within the community. Mixed and separate discussions ensured diverse perspectives from both men and women, with participants receiving refreshments and tokens of appreciation.

Recorded interviews and photographs, taken with consent, were securely stored on Reading University's (UK) OneDrive cloud account with protected access to ensure data security. Data analysis involved coding interview transcripts, using NVIVO 14, into specific themes and extracting relevant direct quotations to supplement structured interview data. A pilot study interview was conducted resulting in minor adjustments to the protocol based on the pilot results. This multifaceted qualitative approach, including in-depth interviews, FGDs, photovoice, and observations, ensured the validity and reliability of findings by representing various stakeholder viewpoints.

Ethical approval and informed consent protocols were strictly adhered to, ensuring the study's compliance with ethical standards. By integrating the RUDSHAM framework with rigourous research methods, the study provides valuable insights for policymakers, researchers, and practitioners focused on promoting sustainable energy transitions in Zambia and other developing countries.

Figure 33: Map of Zambia (UN 2022)

7.5 Research Findings

The empirical data findings in this study examine the critical role of social learning in the adoption of solar PV technology in rural Zambia. Evidence presented in the findings demonstrates how social learning, through observational learning and neighbour influence, shapes community interest and willingness to engage with solar PV. Specifically, the findings showcase various motivations, such as community members' desire for improved energy access and economic opportunity, while also addressing barriers, including economic constraints and limited technical knowledge, which affect the adoption process. These dynamics are analysed within the rural Zambian context, where peer influence and visible examples of successful PV installations provide significant social learning cues that encourage adoption. Further detailed direct quotations are provided in Appendices F and H.

7.5.1 Social Influence Dynamics

Empirical findings in Table 30 highlight the organic adoption of solar technology in rural areas, driven primarily by peer influence, exposure, and practical benefits. Observing neighbours' solar systems for lighting, irrigation, and phone charging encourages wider adoption. Households often acquire systems through informal loans, savings, or family support. Children also play a role by urging parents to improve living conditions. The spread of solar energy knowledge occurs through community interactions rather than formal programmes, as no aid agency distributes solar panels or mobile phones. This self-driven uptake shows the perceived value of solar technology. Once benefits are realised, households willingly invest in upgrades, fostering increased productivity and economic resilience. Community-led diffusion has proven effective in driving solar adoption and improving rural livelihoods.

When individuals learn or observe behaviours or habits that are beneficial to others, especially those they closely associate with, they are highly likely to be influenced to engage in similar behaviour. Individual desires ultimately drive community adoption when aggregated. This underlines the power of observation and peer influence. Initially, when individual community members have not observed or experienced the benefits of some services or products, they may question the need to pay but this perception changes as soon as there is an understanding and appreciation of the product/service benefit.

Table 30: Social Influence Dynamics Direct Quotations

Participant	Aspect	Representative Illustrative Quote
Mkushi Interview 4	*Social Influence*	*"I observed that the houses of my neighbours had good lighting systems and out of interest, I inquired. I discovered you could get a system through a loan and pay slowly over two years through the mobile telecommunication companies. I did not hesitate and quickly organised some funds, and now I do not have to sleep in the dark and be afraid of being bitten by poisonous snakes."*
Chongwe Interview 4	*Social Influence*	*"I have a solar system that helps me with irrigation. I got the idea from my friend who could grow crops during the dry season. I was shocked and excited at the discovery. I found out the price and the source, organised resources through selling some of my produce, and my children in the city also helped. Now I can enjoy winter maize and water my garden. It also helps me raise income."*
Kapiri Discussion (FGD) 2	*Social Influence*	*"We have come to learn about various systems of solar energy that can be used for irrigation, lighting, and phone charging through intermingling with each other, and now, in this village, everyone has at least one solar-powered gadget or another. The knowledge of solar energy devices has been spreading like wildfire around the whole village."*

7.5.2 Community Engagement Deficit

Empirical evidence in Table 31 demonstrates that development projects often suffer due to inadequate community consultation and context alignment. Free stoves, promoted for efficiency, were largely unused as they failed to meet local cooking needs, reflecting a lack of engagement in design and implementation. Rural farmers express frustration with urban based decision making, disconnected from rural realities. Political engagement on solar energy is minimal, leaving awareness primarily through informal channels. Community members stress the value of local input for project success but are often sidelined, leading to failure. Aid agencies' interventions, focused on immediate aid over sustainable development, are perceived as wasteful or poorly planned.

Solar panels are widely accepted within the community as a reliable source of energy. Community members highlighted that consultation plays a crucial role in the design and implementation of solar projects, ensuring alignment with local needs and preferences. Ongoing engagement and feedback mechanisms facilitate continuous improvement and expansion of solar initiatives, although challenges related to infrastructure funding may impede scalability and inclusivity. Unfortunately, no collaboration or consultation with the community was identified at the time of this research, which poses a great risk to the sustainability of solar projects because the intended project beneficiaries are not sufficiently involved in building a strong sense of ownership.

Table 31: Community Engagement Deficit Direct Quotations

Participant	Challenge	Representative Illustrative Quote
Chongwe Interview 4	*Lack of Community Involvement*	*"They brought some free stoves that they claimed used less coll. Although we all got the stoves, we do not use them because they cannot cook our food like charcoal or firewood due to insufficient heat. The only reason we accepted the so-called improved braziers was because they were free. No one consulted us when creating the braziers. NGOs (aid agencies) are in the habit of wasting money…or maybe someone from the higher offices benefited economically from them, you never know."*
Kapiri Discussion (FGD) 1	*Lack of Community Involvement*	*"We can all testify here that you are the first person who has come to interview and talk to us about solar. We just learn about solar energy from our neighbours and when we visit the city or some white farmers' houses."*
Mkushi Discussion (FGD) 2	*Lack of Community Involvement*	*"We might be uneducated, but there is something we can offer, especially pertaining to projects that are implemented in our villages. We know better because we have lived here all our lives, but we are not involved at all, which causes many projects to fail."*

7.5.3 Ownership and Sustainability

Findings in Table 32 highlight a lack of community consultation in development projects, resulting in limited ownership, neglect, and vandalism. Free projects often fail without community investment or accountability mechanisms. Rural people feel disconnected from externally planned initiatives, contributing to apathy and misuse. Conversely, projects with community involvement, such as primary school construction, foster pride and sustainability. Contributions to water systems through payments and labor reflect a willingness to engage when there is ownership and responsibility. The breakdown of poorly managed government-provided assets, such as solar hammermills, illustrates the ineffectiveness of top-down approaches. While free projects are appreciated, they lack durability and long-term success without proper management and community participation.

Historically, communities have become reliant on external aid, resulting in a cycle of dependency where aid agencies provide infrastructure without establishing mechanisms for sustainable maintenance (Observation of the interviewees). This approach leads to a high rate of project failure and non-functional infrastructure in the long-term. Encouraging communities to take ownership of projects fosters a sense of responsibility. Rather than perpetuating the narrative of poverty and dependence, empowering communities to contribute financially instils a sense of worthiness and agency. This engagement may open up opportunities for novel financial arrangements for emerging technologies at either the community or individual level.

Table 32: Ownership and Sustainability Direct Quotations

Participant	Challenge	Representative Illustrative Quote
Kapiri Interview 2	*No sense of ownership.*	*"No one consults us. They just implement projects that are already designed elsewhere. Hence, most people, to be honest, do not feel a true sense of ownership at the individual or community level. That's why there is a lack of care, stealing, and vandalism."*
Mkushi Interview 2	*No sense of ownership.*	*"Who is supposed to watch over the free projects that are implemented in our villages? Is it the headman or the community? It's like it's no one's business, and if there is no one to watch over something, it dies naturally. It's like a motherless baby... it can't survive... Laughs."*
Kapiri Discussion (FGD) 2	*No sense of ownership.*	*"We feel like the primary school in the village is part of our own property because, when it was being constructed, each household had to contribute building blocks and other materials that we could manage. It's not much but I feel proud to have contributed and now my children can go to school without walking many miles. The headman and elders coordinated the contributions."*

7.5.4 Solar Quality Challenges (Counterfeits)

Empirical evidence in Table 33 highlights significant issues with solar product quality, particularly due to an influx of low-cost and counterfeit products, often from China, leading to frequent product failure and financial losses for rural consumers. Vendors and shops commonly refuse returns, leaving consumers unable to repair broken gadgets. Affordability pressures, worsened by poor agricultural seasons, drive rural communities to purchase subpar products that quickly break. Counterfeit solar panels are pervasive, with many containing non-functional or purely decorative parts, deceiving buyers about their true capacity. While reputable dealers provide quality products, they are less accessible. Commercial farmers typically avoid counterfeits and use high-quality sources, but rural users often rely on counterfeits, acknowledging their limitations yet accepting their utility due to limited options.

Effective communication regarding solar panel availability, the need for expertise, and the risk of counterfeit products is essential to supporting successful solar PV adoption in rural communities. The ready accessibility of solar panels through numerous local shops highlights the widespread availability of this technology. However, the perceived prevalence of counterfeit and substandard panels remains a significant issue, as consumers often struggle to differentiate between genuine and inferior products; peer information dissemination of this issue serves to undermine trust in PV technology. In this context, rural farmers, typically highly price-sensitive, are particularly susceptible to purchasing unreliable or ineffective solar products, especially without established consumer standards for product quality.

Data gathered in this study supports the presence of social learning mechanisms to address these challenges. Community members increasingly share information on which dealers offer reliable products, providing informal guidance that emphasises the importance of quality assurance and expert consultation. Observational learning within the community also plays a role, as individuals observe and adopt the practices of others who successfully use solar technology sourced from reputable suppliers, reinforcing a cautious yet proactive approach to PV adoption.

Table 33: Solar Quality Challenges (Counterfeits) Direct Quotations

Participant	Challenge	Representative Illustrative Quote
Chongwe Interview 2	*Counterfeits*	*"The solar panels I have are very big but not very powerful. When my brother from the city visited, he told me that most of the panel was just decoration and only a small part was used for solar production."*
Kapiri Discussion (FGD 2)	*Counterfeits*	*"Most of us keep buying new solar gadgets every now and then because most of them are Chinese. We have disposed of a lot of them…ha ha…but what can we do? The counterfeits are affordable."*
Mkushi Discussion (FGD 1)	*Counterfeits*	*"Most of us, because of a poor farming season, just buy the cheapest and most affordable gadgets we can find on the market, and sadly, cheap is expensive. But honestly, we have no option. And when these gadgets break, there is no way to repair them, so it's a loss."*

7.5.5 Entrenched Poverty and Tradition

Findings in Table 34 indicate deep-rooted feelings of neglect and marginalization in rural communities, leading to resignation about poverty and skepticism toward external aid. Traditional practices in medicine, agriculture, and family structures are valued, with some resisting modernization and outside intervention due to perceived disrespect. Education is seen as secondary to family building, although there is recognition of its potential. Shifting from a post-paid to a prepaid water system showed positive changes in engagement, highlighting the importance of self-initiative. Generational cycles of poverty create mental barriers, with defence mechanisms that protect but can hinder progress. Encouragement and exposure to opportunities can help individuals break these cycles and foster growth.

A number of commercial farmers highlighted the need to address cycles of poverty through a shift in mindset, as they perceived that deeply ingrained attitudes and self-defence mechanisms often hinder progress. Commercial farmers cited a "poverty mentality", described as a complex phenomenon, limiting both material resources and rationale processes, preventing individuals from seizing advancement opportunities. They went on to suggest that interventions by aid agencies frequently overlook mindset issues while aiming to remain sensitive to the physical contexts of adopters. They suggest that the oversight of prospective user rationale undermines the effectiveness of development programmes. It was suggested that a holistic approach to poverty alleviation must address both material needs and psychological barriers. Comprehensive education on poverty and rural people's mindsets is crucial yet often neglected, leaving donors with a superficial understanding of poverty's complexities.

Effective poverty interventions must integrate strategies for mindset transformation with traditional development initiatives, recognising the interplay between material resources and mental attitudes in fostering sustainable change.

Table 34: Entrenched Poverty and Tradition Direct Quotations

Participant	Challenge	Representative Illustrative Quote
Kapiri Interview 1	*Community Negative Mindset*	*"We were born in poverty, grew up in poverty and we will probably die in poverty together with our children because no one cares about us including our own leaders."*
Chongwe Interview 2	*Community Negative Mindset*	*"I don't need assistance from anyone as I have managed to live and survive using the knowledge that I have acquired from within the community. I do not need to be modern or to learn anything extra."*
Kapiri Discussion (FGD) 2	*Community Negative Mindset*	*"We have traditional systems that have worked for us in the areas of medicine, marriage, agriculture, sustainability for hundreds of years which we will hold on. Someone can't just come from outside and tell us what to do. That is disrespectful and offensive. That's why even projects from aid agencies fail."*

7.5.6 Aid Effectiveness and the Importance of Sustainability

Findings in Table 35 indicate that many aid agencies fail to address poverty's psychological and attitudinal roots, fearing political backlash. Their reluctance to make communities pay for services like solar and water systems results in unsustainable outcomes, with broken infrastructure often left unmaintained after funding ends. Donors often prefer providing free aid to meeting targets, overlooking self-sustaining models. This approach fosters dependency and undermines community autonomy. In contrast, communities value services they invest in, finding ways to pay for necessary repairs. Aid agencies frequently opt for short-term solutions over sustainable, business-oriented approaches due to donor resistance and lack of nuanced understanding. There is criticism that donor motivations are often self-serving, preferring emotionally appealing free aid over meaningful, skill-based support that builds self-reliance and dignity. Donors, often uninformed about the complexities of poverty, may prefer to address immediate needs without considering the long-term implications. This results in a reluctance to invest in initiatives that require sustained support, perpetuating the dependency syndrome rather than fostering self-sufficiency. By recognizing the value of important lifesaving services and actively seeking ways to afford them, individuals are motivated to increase productivity and pursue economic opportunities. Acknowledging the worth and capabilities of community members is essential for preserving dignity and promoting self-esteem. Offering services for free can undermine the perceived value of individuals and perpetuate cycles of dependency.

Cultivating a culture of contribution and reciprocity enhances community resilience and self-sufficiency. When individuals recognise the value of their contributions, they are more inclined to participate actively in initiatives aimed at improving their quality of life. The importance of recognizing and respecting the inherent value of an individual's contribution cannot be over emphasised. This is because by valuing the contributions of community members and fostering a culture of mutual respect, initiatives can effectively promote sustainable development while preserving human dignity.

Table 35: Aid Effectiveness and the Importance of Sustainability Direct Quotations

Participant	Challenge	Representative Illustrative Quote
Commercial Farmer Interviews 2	*NGO Mindset*	*"One of the biggest failures of the NGO community is their reluctance to address the mindset issue. They avoid it, partly because they fear appearing politically incorrect. This hesitance undermines aid programmes, as they do not tackle the deeper roots of poverty, many of which stem from mental and attitudinal barriers."*
Commercial Farmer Interviews 7	*NGO Mindset*	*"We frequently clash with large donor agencies like UNICEF, World Vision, and USAID over making communities pay for services. Questions like who will fix a broken pipe or replace a solar panel remain unresolved when systems are provided for free. This lack of sustainable planning is a major issue."*
Commercial Farmer Interviews 16	*NGO Mindset*	*"NGOs often install free systems but do not stick around once their funding ends. This leads to high failure rates, as evidenced by communities where over 70% of boreholes are nonfunctional. Sustainable solutions require a consistent revenue source, meaning communities must pay for services like solar electricity to ensure lasting success."*

7.5.7 Project Misalignment and Dead Aid: Challenges of Implementation

Findings in Table 36 highlight a lack of meaningful consultation and follow-up in rural aid projects. Solar PV initiatives remain under-discussed, while political campaigns focus narrowly on farming and water needs. Equipment distributed to farmers often goes unused or poorly maintained due to inadequate training. Free stoves with insufficient heat fail to meet community cooking needs, and mosquito nets are misused due to limited education. Aid projects, such as women's loans, lack necessary training and oversight, leading to poor outcomes. Schools and clinics are built without essential support staff, and livestock distribution efforts falter without veterinary care. Community needs and practicalities are often overlooked, leading to misaligned, wasteful, or underutilised projects.

There is often a disconnect between the needs of the recipient community and the offerings of government officials and aid agencies. The self-serving nature of much humanitarian giving raises the critical need to distinguish between providing aid and investing in sustainable development. Donors may give to fulfil personal satisfaction without a genuine interest in the long-term impact of their contributions. Consequently, aid organizations may prioritise short-term relief efforts over sustainable development initiatives. Disparities in resource allocation within aid organizations highlight systemic issues that hinder long-term development. While immediate relief efforts receive substantial funding, initiatives aimed at encouraging sustainable solutions often struggle to secure adequate support. This discrepancy undermines efforts to empower communities and promote self-reliance.

Table 36: Project Misalignment and Dead Aid Direct Quotations

Participant	Challenge	Representative Illustrative Quote
Chongwe Interview 4	*Misaligned Aid.*	*"They brought some free stoves that they claimed used less firewood. Although we all got the stoves, we do not use them because they cannot cook our food like charcoal or firewood due to insufficient heat. The only reason we accepted the so-called improved braziers was because they were free. No one consulted us when creating the braziers. NGOs (aid agencies) are in the habit of wasting money… or maybe someone from the higher offices benefited economically from them, you never know."*
Kapiri Discussion (FGD 1)	*Misaligned Aid.*	*"Some of the projects that have been implemented here are good, but again there are many projects which are clearly misaligned and have just been a waste of time and money. For example, health programmes for distributing mosquito nets ended up with nets being used for fishing because of a lack of adequate training. Loans were given to many women without adequate financial literacy training, resulting in misuse of funds and difficulty in repayment."*
Mkushi Discussion (FGD) 1	*Misaligned Aid.*	*"We received free energy-saving braziers that were distributed in various villages but ended up being unused due to insufficient heat for cooking local staple foods like maize meal (nshima), which requires high temperatures. Schools were built without accompanying teacher housing or water and sanitation facilities, causing high teacher turnover and limited utilization of the infrastructure. Yes, the buildings are there, but there are no teachers. There are clinics but no doctors. There are bee-keeping training programmes that were introduced as a source of livelihood, but people sometimes struggle to sell the honey due to difficulties in accessing markets."*

7.6 Technological Adoption Despite Resource Scarcity: Case Studies

A number of case studies were raised during the primary data collection that emphasise their relevance for future rural PV adoption as it pertains to social learning. These focused on similar technological interventions as they are either emerging or infrastructural, as well as being adopted in rural areas. These included mobile phones, solar PV chargers, PV torches, and piped water.

7.6.1 Adoption of Mobile Phone and Lighting

The first illustration (refer to Appendix F for details), comes from mobile phones, solar PV phone chargers, solar PV lighting systems and/or solar PV torches. The overwhelming majority (>80%) of rural people engaging in focus groups and semi-structured interviews in the four regions covered own mobile phones, solar PV phone chargers, solar PV lighting systems and/or solar PV torches. Further, a substantive share (around 20%) owns smart phones. In addition to being able to pay for the initial devices, rural people surveyed were also able to pay for ongoing usage (e.g., prepaid airtime). As noted earlier, no land lines are available in rural Zambia and mobile phone communication towers have negated the use of landlines and leapfrogged their usage (James, 2016, 2012, 2009). The findings emphasise the significance of social learning in promoting the adoption of solar energy technologies, including solar PV chargers and solar lights/torches, among rural farmers in Zambia.

The cultivation of social networks among community members reinforces the importance of collective experiences, thus contributing to the broader uptake of solar technologies in rural settings and illustrating the intersection of social norms and practical needs in fostering sustainable energy solutions. The observed benefits of mobile phones, solar PV phone chargers, solar PV lighting systems, and solar PV torches in rural Zambia emphasise the importance of social learning in technology adoption, which can similarly drive solar energy initiatives. Community members' success stories regarding improved connectivity, enhanced safety, and increased productivity illustrate how witnessing positive outcomes among peers encourages collective interest and adoption of such technologies.

7.6.2 Piped Water Adoption in Rural Setup

Another pertinent illustration (refer to Appendix G for further details) comes from piped water adoption. Literature has shown that on average rural Zambians live on less than $1.9/day (Kalle Hirvonen, Elia Machado, 2024; Mudenda et al., 2023; Sharon Handongwe, 2017). However, from discussions in interviews with the director of the aid agency Access Water for Zambia, it was claimed that, as of 2023, over 85% of rural people in a case study (Samfya rural and Mbabala Island) area were connected to piped water systems (Regional Programme Manager, Access Water for Zambia (Water4), Samfya, Luapula Province). Most of these households (~1200) were on prepaid metres and $40,000 (the equivalent of 125,000 litres) in annual sales in the

2022/23 financial year (or ~$33 per household per year on average) was collected. The observed benefits of piped water systems in rural areas underscore the significance of social learning in technology adoption, which can be applied to solar energy initiatives. The success stories shared by community members regarding improved health, reduced disease incidence, and enhanced daily productivity illustrate how witnessing the positive outcomes of peers fosters a communal desire for similar advancements, such as solar PV chargers and lights. These narratives build trust and confidence among residents, motivating them to adopt solar technologies as they perceive these innovations as valuable solutions to their energy challenges, analogous to the acceptance seen in water system implementations.

These case studies demonstrate that if the correct drivers for adoption are established, lower income rural people can find the means to pay for new technologies and their associated services to receive substantive and observable benefits. Elaboration on the lessons that can be taken from these with respect to social learning are discussed below.

7.7 Interpretation and Discussion

7.7.1 Observational Learning and Peer Influence

From the focus groups and interviews carried out, many participants identified peer learning aspects that led to their adoption of PV or their learning about PV as a useful and helpful technology. The role of peer influence and observational learning in technology adoption has been widely acknowledged in literature. For instance, studies have shown that observing peers who benefit from a new technology significantly impacts an individual's decision to adopt that technology (Rogers, 2003a; Turner, 2007). The rapid uptake of mobile phones in rural areas, which bypassed traditional landline infrastructure due to their user-friendly nature and relative infrastructural simplicity exemplifies this phenomenon. In the case of mobile phones, users in this research have identified several clear benefits (see appendix F) which were readily observable for other prospective users to understand and learn from. For instance, when mobile phones were seen to facilitate market access for agricultural commodities, these experiences and benefits were readily shared amongst community members exemplifying social influence phenomenon. This aligns with the RUDSHAM attribute of Perceived Ease (PE), where technologies perceived as easy to use are more likely to be adopted. Contrastingly, some research suggests that while peer influence is significant, it must be accompanied by adequate infrastructure and support systems to sustain long-term adoption (Shakeel and Rajala, 2020). This highlights the need for comprehensive strategies that not only leverage social influence but also ensure supportive environments for solar PV adoption in rural Zambia.

Meanwhile, the negative experiences shared by peers, such as counterfeit PV panels, could serve to undermine the adoption of drivers as rural dwellers are less likely to engage in risky purchasing. Given the long-term investment required for PV and the substantial outlay of income relative to mobile phone technology, trust and quality control may be even more important in the case of PV due to the greater risk involved. This aligns with findings from extant literature (Samarakoon et al., 2021).

7.7.2 Dependency and Sustainability

For successful adoption to occur, intrinsic motivation at both the individual and community levels is essential, as demonstrated in the case studies of mobile phones, piped water systems, and other solar technology devices. Additional information on aid dependency and the sustainability of aid initiatives is provided in Appendices F and G. The issue of dependency on external aid and the resulting unsustainable infrastructure is well documented. Studies indicate that reliance on government and aid agencies' interventions without local involvement often leads to project failures (Antwi and Ley, 2021; Creamer et al., 2019; Ikejemba and Schuur, 2020; Mooney, 2009). Encouraging community ownership (Community Participation) is essential for sustainable development. Involving local communities in the planning and maintenance of projects can foster a sense of responsibility and ensure long-term functionality as evidenced in the mobile phone and piped water adoption case studies. This perspective is supported by recent research emphasizing the importance of local engagement and ownership in successful development projects (Ikejemba and Schuur, 2020; Walker and Devine-Wright, 2008). However, some critics argue that without substantial initial external investment and technical support, community-driven projects may struggle to achieve scalability and impact (Duncan, 2016; Sovacool, 2013). This underscores the need for a balanced approach that integrates both external support and community involvement for sustainable solar PV adoption.

7.7.3 Mindset Transformation and Poverty

Several interviews highlighted the psychological aspects of poverty as a crucial barrier for fostering sustainable development. Previous research emphasises that ingrained mindsets around being trapped in poverty, an entitlement of support from stakeholders who are perceived to be more affluent, and self-defence mechanisms when support is withheld can hinder progress, making mindset transformation a vital component of development strategies (Rehman et al., 2012). Integrating these strategies with traditional development efforts can significantly enhance outcomes. For example, in rural Zambia, CARE International implemented the Village Savings and Loan Association (VSLA) programme to address poverty mindsets by fostering financial self-reliance among participants (Bwalya and Zulu, 2021; Care, 2020). Additionally commercial farmers interviewed suggest that they are helping rural farmers to cut out middlemen and add value to their products to increase the profits. This aligns with the RUDSHAM attribute of Perceived Behavioural Control (PBC), where individuals' perceptions of their ability to influence outcomes affect their engagement in development initiatives. However, this approach is often overlooked due to fears of "political incorrectness" or the desire to correct disparities such as historic colonial oppression leading to current poverty or to disparities associated with rural/urban wealth distribution (Barke, 2023; Moller, 2015; Molotsky and Handa, 2021). Critics argue that focusing on psychological aspects alone without addressing structural (i.e., psychological) and economic barriers may not yield substantial results (Wanodyo, 2012). Therefore, a comprehensive approach that addresses both psychological and structural factors will be essential for effective solar PV adoption in rural Zambia.

7.7.4 Donor Motivations and Investment Sustainability

Despite some positive examples of aid agencies performing well, such as OXFAM (funded by DFID), which implemented a five-year project in communities within the Copperbelt Province, achieving sustainability outcomes through the multi-sector forum model approach, later scaled up by the Zambian government. Another issue highlighted in the findings is the perception that some aid agencies prioritise immediate relief over long-term sustainability. This approach has been criticised for perpetuating ineffective aid models (Kharas, 2007). This was reviewed from the findings where many USAID projects had taken off well only to fall shortly due to lack of practical sustainability plans. Treating development services as commodities and empowering communities to invest in their own progress can lead to more sustainable outcomes, as suggested by recent literature (Andrews et al., 2017). This aligns with the RUDSHAM attribute of Policy Support (PS), emphasizing the need for policies that promote community investment and self-sufficiency. However, some argue that immediate relief is necessary to address urgent needs and that long-term strategies should complement rather than replace short-term aid (Sachs, 2008). This calls for a balanced approach that integrates immediate relief with strategies for long-term sustainability in promoting solar PV adoption.

7.7.5 Information Dissemination and Community Involvement

Effective dissemination of information and community consultation are crucial for technology adoption. Limited marketing efforts and reliance on informal knowledge channels hinder widespread adoption, as evidenced in recent studies (Rai and Beck, 2015). Engaging communities in the design and implementation of projects ensures that local needs and preferences are met, encouraging greater acceptance and uptake (Norms, NO). This perspective is supported by research highlighting the importance of tailored communication strategies in promoting new technologies (Alfaro and Miller, 2021; Miller and Buys, 2008). Conversely, some researchers argue that overemphasis on consultation if not done properly can delay implementation and dilute the effectiveness of interventions (Maka and Alabid, 2022). Therefore, striking a balance between community consultation and efficient implementation is key for successful solar PV adoption.

The discourse surrounding the adoption of solar energy technologies in rural Zambia emphasises the crucial roles of observational learning and peer influence in information dissemination. Observing peers benefiting from new technologies significantly shapes individuals' decisions to adopt similar innovations, as evidenced by the rapid acceptance of mobile phones, solar chargers, solar PV lighting, solar torches and piped water in rural communities. Moreover, community participation and ownership are essential for sustaining these technologies, as projects often fail without local engagement. Additionally, addressing psychological barriers to change and fostering a mindset transformation are vital for enhancing community members' perceptions of their ability to engage in development initiatives. Moreover, there is a need for balanced approaches that integrate external support from government and aid agencies with community involvement. There should be emphasis on effective information dissemination to facilitate technology uptake, aligning with the broader themes of social influence in technology adoption.

7.8 Recommendations

Based on the findings and conclusions of this study, the following recommendations provide a systematic and logical framework for fostering the sustainable adoption of solar photovoltaic (PV) technology in rural Zambia. These recommendations aim to address barriers, promote community empowerment, and contribute to sustainable poverty alleviation. By implementing these recommendations, it is posited that the Zambian government can create an enabling environment for the sustainable adoption of solar PV technology in rural areas. The strategic integration of peer influence, community participation, mindset transformation, policy support, tailored solutions, and financial models will address the unique challenges faced by rural communities, ensuring that solar PV systems contribute to poverty alleviation and community empowerment.

7.8.1 Leverage Peer Influence for Technology Uptake

To facilitate the adoption of solar PV technology, the government, in collaboration with aid organizations and development banks, should harness the power of peer influence and observational learning. Peer-led demonstrations, conducted by local champions who have successfully adopted solar technologies, can showcase the tangible benefits of these systems and build trust within communities. The Ministry of Energy and the Rural Electrification Authority (REA) should play a key role in supporting these efforts by improving accessibility and infrastructure in rural areas. Leveraging peer influence in this way will increase the visibility and credibility of solar technology, encouraging its wider adoption.

7.8.2 Foster Ownership Through Governance Structures

Community ownership and participation are vital for the sustainability of solar PV initiatives. Local governance structures, such as Ward Development Committees (WDCs), should be actively involved in the planning, implementation, and maintenance of solar projects. Strengthening WDCs, as outlined in Zambia's District Integrated Development Plans and supported by the Local Government Act No. 2 of 2019, is crucial for promoting citizen participation. However, WDCs currently face challenges such as insufficient resources, lack of training, poor communication, and political interference. To address these limitations, the government should implement capacity-building programmes, improve communication channels, and provide adequate resources to enable WDCs to fulfill their roles effectively. These measures would empower communities to take ownership of solar PV initiatives, fostering accountability and long-term sustainability.

7.8.3 Integrate Mindset Change in Development

Mindset transformation is critical to overcoming psychological barriers, such as entrenched poverty mindsets and dependency on external aid. For example, The Ministry of Education and the Ministry of Gender, in partnership with aid agencies like Plan International, should integrate psychological empowerment workshops into solar PV programmes. These workshops should focus on fostering self-efficacy and promoting a culture of self-reliance. Coupled with infrastructure support, such initiatives have the capacity to enhance individuals' perceived behavioural control over adopting new technologies, ensuring deeper community engagement and commitment to solar PV adoption.

7.8.4 Promote Policy Support for Sustainable Investments

The Ministry of Finance, in collaboration with donors such as the World Bank, should implement policies that encourage sustainable investments in solar infrastructure. Co-financing models that require partial contributions from communities can empower local populations to take financial ownership of solar PV systems. By prioritizing community driven investments, the government can reduce dependency on short-term relief while promoting long-term sustainability. Policies that incentivise donor and private sector partnerships hold the potential to ensure that solar PV systems remain operational and accessible over time.

7.8.5 Enhance Information Dissemination and Community Consultation

The adoption of solar PV technology depends on effective information dissemination and active community consultation. For example, The Ministry of Information and Broadcasting Services, in partnership with organizations like Oxfam, should develop tailored communication strategies that align with local cultural norms and languages. These efforts should educate communities about the benefits, costs, and reliable sources of solar PV products, ensuring informed decision-making. Furthermore, integrating comprehensive consultation processes would help address community-specific needs and preferences, ensuring the relevance and acceptance of solar PV initiatives. Such a participatory approach provides the means to foster trust and enhance the likelihood of widespread adoption.

7.8.6 Develop Financial Models for Affordable Access

The high upfront costs of solar PV systems remain a significant barrier for rural households. To address this issue, the government should promote flexible financial models, such as pay-as-you-go (PAYG) schemes and micro-loans, to enable incremental payments for solar systems. Companies like Fenix International have successfully implemented such models in Zambia, demonstrating their feasibility. By incorporating these approaches into national energy policies, the government would be in a better position to enable access for low-income households to clean and affordable energy, reducing financial constraints as a barrier to adoption.

7.8.7 Tailor Solar Solutions to Local Needs

To ensure meaningful adoption, solar PV solutions must align with the specific energy demands of rural communities. The government should prioritise the development of practical and scalable systems, such as solar-powered water pumps for agriculture and small-scale solar micro-grids for rural clinics and schools. By addressing local needs and integrating solar technology into existing development initiatives, such as agricultural and healthcare programmes, the government would have the opportunity to demonstrate the tangible benefits of solar PV technology. This approach will not only improve productivity and social development but also enhance the acceptance and long-term sustainability of solar solutions.

7.9 Conclusion

Recognising individual benefits is a powerful motivator for acquiring and financing services within rural communities. The impact of peer observation and social dynamics is evident, as individuals are more likely to adopt beneficial behaviours when they see positive outcomes among their peers. The widespread adoption of mobile phones in rural areas, bypassing landlines, illustrates the preference for user-friendly and convenient technologies. This pattern shows that ease of use and perceived advantages are key drivers of significant technological transitions.

While external aid provides short-term relief, it is not a sustainable long-term solution. Assistance can only be maintained for so long before it becomes impractical, making it essential to develop local solutions rather than relying on continuous external support. The recent reduction of aid to many countries under the Trump administration highlights the risks of dependency and should serve as a wakeup call for nations and communities heavily reliant on foreign assistance. Achieving sustainable development requires self-sufficiency and proactive problem solving at the local level. Historically, reliance on outside support has created dependency, with policymakers and aid agencies often failing to establish lasting maintenance mechanisms. Promoting community ownership of projects instills responsibility, encourages self-reliance, and helps preserve dignity. Additionally, effective marketing and clear communication are essential for the widespread adoption of solar PV. Ensuring access to reliable information and involving communities in decision-making significantly enhance adoption rates.

A lack of thorough research and potential biases can compromise the validity of findings, highlighting the need for rigourous and objective research methodologies. Strengthening project sustainability and achieving long-term progress require a comprehensive approach, one that emphasises individual benefits, encourages donor-driven research on the complexities of poverty, and promotes shifts in community mindsets toward independence. As a contribution to knowledge, we developed the Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM), an innovative framework that integrates three key theoretical perspectives to provide a comprehensive understanding of the factors influencing renewable energy adoption in rural areas. This framework accounts for the interconnected effects of individual perceptions, social influences, and community engagement in shaping adoption behaviours. By offering insights into the complexities of solar PV adoption, RUDSHAM serves as a valuable tool for policymakers, researchers, and practitioners working to develop effective strategies for sustainable energy transitions in rural communities.

7.9.1 Study Limitations and Future Research Recommendations

- Study Duration
  The six-month study period, from October 2022 to March 2023, provided valuable insights but limited the ability to observe long-term adoption patterns, seasonal influences, and system durability in rural communities. Extending the study duration in future research would allow for a more comprehensive understanding of these dynamics.
- Geographic Scope and Funding
  Due to funding constraints, the research was limited to three rural areas in Zambia, reducing the geographic and cultural diversity of the sample. Future studies could benefit from broader funding to include additional regions, enabling more generalizable findings for rural sub-Saharan Africa.

Chapter 8: The solar E-waste challenge: A Zambian case study of informal disposal, counterfeit technologies and low literacy. (Article 4)

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Summary: This article explores the under-researched and urgent issue of solar photovoltaic (PV) electronic waste (e-waste) in rural Zambia, where the rapid expansion of off-grid solar systems is generating complex sustainability challenges. Despite contributing to SDG 7 on energy access, the proliferation of low-cost, often counterfeit PV technologies in off-grid regions has led to an emerging crisis of informal disposal practices. These include open burning, burial, and unsafe repurposing, activities that pose environmental and health risks.

Abstract: Findings reveal that rural households frequently lack the technical literacy and institutional support necessary to properly manage end-of-life PV components. The study highlights how market saturation with substandard products, deceptive sales tactics, and weak regulatory enforcement collectively drive unsustainable disposal behaviours. Furthermore, formal e-waste collection systems are virtually non-existent in rural Zambia, exacerbating ecological degradation and widening energy justice gaps.

Recommendations: The article calls for an urgent policy response that integrates solar e-waste management into national energy and environmental frameworks. Key recommendations include establishing decentralised collection centres, regulating informal solar markets, and embedding culturally relevant solar literacy programmes within rural communities. These interventions should be accompanied by the development of user-centred take-back schemes and locally operated repair hubs.

Overall contribution: The study advances Thesis Objective 3 by critically assessing post-adoption system reliability, disposal practices, and consumer vulnerability. It enriches the thesis's overall argument by illuminating how unregulated technological diffusion, when detached from education and oversight, can inadvertently intensify environmental injustice in vulnerable rural contexts.

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Keywords: Solar e-waste, Informal Disposal, Counterfeit Technologies, Literacy, Rural SSA, Zambia, Sustainability Transitions

8.1 Introduction

The exponential growth of off-grid solar photovoltaic (PV) systems in Sub-Saharan Africa (SSA) has emerged as a pivotal pathway to achieving Sustainable Development Goal 7 (SDG 7); ensuring affordable, reliable, sustainable, and modern energy access for all (Keane et al., 2024; Munro et al., 2023b). Propelled by technological advancements, cost reductions, and innovative market-based business models, the solar sector has revolutionised energy access in dispersed, off-grid communities where traditional electrification remains financially and logistically prohibitive (Chanda et al., 2025a; Nygaard et al., 2016). This surge in adoption is particularly likely to occur in countries like Zambia, where rural electrification rates remain critically low and over 80% of rural households still depend on wood fuel for cooking (Chambalile et al., 2024; Makai and Chowdhury, 2017; ZamStats, 2022)

However, while the rapid expansion of off-grid solar systems offers tangible socio-economic and environmental benefits, it also introduces complex unintended consequences, notably in the form of electronic waste (e-waste) accumulation (Munro et al., 2023b; Nalwamba, 2021). Electronic waste refers to all items of electrical and electronic equipment (EEE) and its parts that have been discarded by its owner as waste without the intent of re-use (UN-ITAR, 2024). Electronic waste is one of the fastest growing and most complex waste streams in the world, affecting both human health and the environment, and proliferating a loss of valuable raw materials. The majority of solar energy kits (SEKs), including lanterns, solar home systems (SHSs), and associated appliances, are designed with short lifespans, often less than four years, resulting in accelerated product obsolescence (Keane et al., 2024; Kinally et al., 2023). The expected surge in discarded solar photovoltaic (PV) panels presents a growing challenge for global e-waste management, with projections indicating a fourfold increase to 2.4 million tonnes by 2030 from 600,000 tonnes in 2022 (see Fig. 34) (UN-ITAR, 2024).

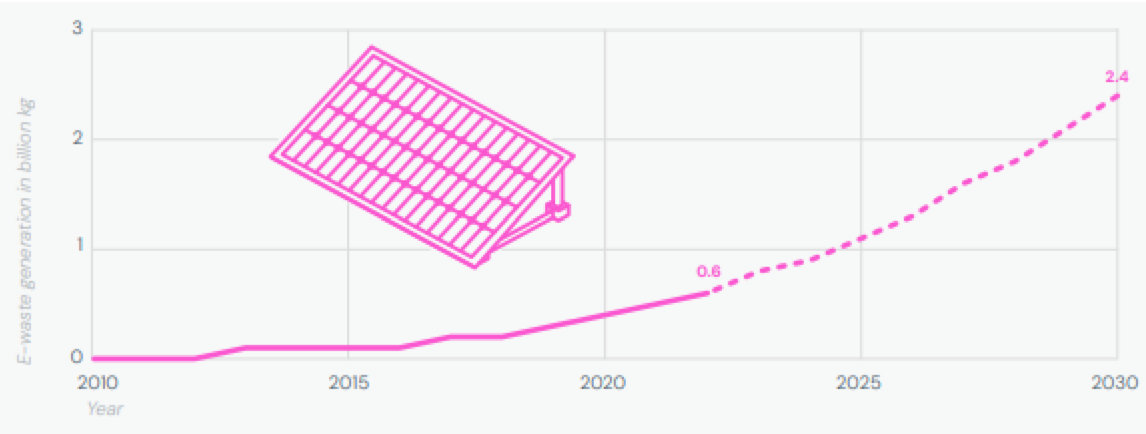

Figure 34: Total E-waste Generated from Photovoltaic Panels (Source: The Global E-waste Monitor 2024)

In Zambia alone, approximately one million small-scale solar products were sold between 2018 and 2022, yet many of these have already ceased functioning, with more than 90% being technically repairable yet rarely serviced (Keane et al., 2024;

Munro et al., 2023a). These dynamics have positioned solar e-waste as a critical and overlooked facet of the clean energy transition, necessitating urgent attention from scholars, practitioners, and policymakers.

Notwithstanding the progress in solar energy adoption, Zambia and SSA at large, continues to grapple with profound systemic deficits in e-waste management infrastructure, regulatory frameworks, and enforcement capacities (Avis, 2021; Hansen et al., 2022; Nalwamba, 2021). Existing waste management practices in these contexts remain overwhelmingly linear and informal, with most e-waste either disposed of through rudimentary methods such as burial, open burning, or repurposing, or exported to neighbouring countries (Kinally et al., 2023; Munro et al., 2023a; Nalwamba, 2021). Informal recycling, particularly of lead-acid batteries, introduces acute health and environmental risks, exacerbated by weak institutional governance, porous borders, and underfunded regulatory agencies (Avis, 2021; Bates and Osibanjo, 2019; Kinally et al., 2023).

Further compounding these challenges is the pervasive influx of counterfeit and substandard solar technologies, often indistinguishable from genuine products due to deceptive labelling practices and weak border controls (Mubita and Chowa, 2021). For low-income, rural consumers, these counterfeit products provide an appealing, albeit problematic, alternative due to their lower prices and immediate availability through informal markets (Munro et al., 2023a). The result is an accelerated accumulation of prematurely failing solar products, fostering a self-perpetuating cycle of energy poverty, environmental degradation, and consumer exploitation (Chambalile et al., 2024; Munro et al., 2023a).

These complexities are further exacerbated by low literacy levels and limited consumer awareness of solar e-waste hazards, particularly in rural Zambia, where illiteracy rates remain high, especially among women (Kanyamuna et al., 2021). Studies from Zambia and across SSA indicate that end-users lack the technical capacity, knowledge, and institutional support to manage solar systems safely and sustainably throughout their lifecycle, including at end-of-life disposal stages (Hansen et al., 2022; Kinally et al., 2023; Mugendi et al., 2024). Consequently, end-users resort to unsafe disposal behaviours such as burning or burying solar panels and batteries, often unaware of the toxic chemicals and health risks involved (Kinally et al., 2023; Munro et al., 2023a).

Despite the growing scholarly recognition of solar e-waste issues in SSA, the discourse remains nascent and heavily concentrated in countries like Nigeria, Ghana, and South Africa, with minimal empirical studies focused on Zambia (Maphosa and Maphosa, 2020). Moreover, few studies explicitly investigate the interplay between informal disposal practices, counterfeit technology proliferation, and socio-cultural factors such as low literacy, leaving critical knowledge gaps that hinder the formulation of context-specific interventions (Keane et al., 2024; Kinally et al., 2023; Munro et al., 2023a). There is also a dearth of applied energy scholarship exploring how these dynamics intersect with broader policy, health, environmental, and socio-economic considerations within the clean energy transition paradigm, particularly for vulnerable rural communities in Zambia (Chambalile et al., 2024).

Against this backdrop, the present study seeks to address these research gaps by investigating the emerging solar e-waste challenge in rural Zambia, focusing specifically on informal disposal behaviours, the prevalence of counterfeit technologies, and the influence of low literacy on e-waste management practices. Through this case study, the study aims to advance energy research by critically examining the underexplored dimensions of solar waste governance, technology justice, and user behaviour in off-grid rural contexts, contributing new empirical insights to inform sustainable energy policy, infrastructure design, and community engagement strategies.

To this end, the study is guided by the following research questions:

- What are the solar waste disposal practices reported in selected study areas within rural Zambia?
- What are the main drivers contributing to solar e-waste challenges in selected study areas of rural Zambia?
- What are the risks and implications for environment, health, and policy?

This study contributes to the expanding body of knowledge on renewable energy transitions, energy justice, and sustainable waste management in low-income settings, aligning with current discourse on applied energy systems, environmental sustainability, and policy challenges in the clean energy transition. By engaging with these issues, the study further supports the United Nations' SDG 7, while highlighting the urgent need for integrated energy-waste governance frameworks that ensure the transition to low-carbon energy systems does not exacerbate socio-environmental vulnerabilities (Avis, 2021; Hansen et al., 2022; Nalwamba, 2021).

8.2 Literature Review

This section examines the nexus between solar electrification and the growing e-waste burden in Sub-Saharan Africa (SSA), with a particular focus on Zambia. The literature is organised thematically to underline the current knowledge base on solar PV deployment, waste generation, governance constraints, consumer behaviour, and the informal solar economy. In doing so, it highlights specific empirical and conceptual gaps that the present study addresses, particularly the absence of rural-focused evidence on solar e-waste pathways, informal market dynamics, and the role of literacy in shaping disposal behaviours.

8.2.1 Solar PV Electrification in Rural SSA

The deployment of solar photovoltaic (PV) systems across off-grid rural regions in SSA has emerged as a key strategy in addressing chronic energy poverty (Chanda et al., 2025a, 2025b, 2025c; Nygaard et al., 2016; Tinta et al., 2023). Technological innovation, declining PV costs, and decentralised, market-oriented distribution models have contributed to their uptake, contrasting with previous donor-led grid expansion efforts (Nygaard et al., 2016). Zambia reflects this broader trend, with a marked increase in solar PV adoption in underserved rural regions. However, affordability challenges, limited maintenance infrastructure, and policy fragmentation constrain deeper integration (Chambalile et al., 2024; Mulenga et al., 2023). Importantly, despite the momentum in solar investment and deployment, there remains a lack of systematic attention to downstream challenges, particularly the management of defective and expired solar components. This omission uncovers a significant research gap: the need to explore how solar systems are disposed of or repurposed once they reach end-of-life in rural, off-grid settings, especially where institutional oversight is weak and market regulation is absent (Munro et al., 2023a).

8.2.2 Solar E-Waste Due to Clean Energy Transition

Although solar PV systems are widely regarded as central to sustainable development, they also contribute to a new and underexplored category of electronic waste. Globally, over 250 million of the 375 million solar energy kits distributed since the early 2000s are estimated to have deteriorated into e-waste (Keane et al., 2024). In Zambia, sales of over 1 million small-scale solar devices between 2018 and 2022 (Munro et al., 2023a) suggest a similar trajectory, particularly given the limited availability of repair services and poor aftersales support in rural zones. This situation presents dual challenges. On the one hand, discarded solar components pose serious environmental and health risks due to the resource-intensive materials they contain (Shokrgozar et al., 2024). On the other hand, if managed properly, the sector offers opportunities for circularity through resource recovery. Avis (2021) notes that the global value of recycled e-waste surpassed €55 billion in 2020. However, how these dynamics unfold in marginalised rural contexts where institutional frameworks are minimal remains insufficiently examined.

8.2.3 Rural SSA E-Waste Disposal Practices

A recurring issue in the literature concerns the prevalence of informal and unsafe e-waste disposal methods in rural SSA. These include open burning, unregulated landfilling, and burial of solar products and associated lead-acid batteries (Kinally et al., 2023). Such practices expose communities to lead and other toxicants, particularly in the absence of accessible recycling infrastructure (Orisakwe et al., 2020). In Zambia, Munro et al. (2023a) document a growing trend of repurposing or discarding failed devices with little awareness of associated risks. Importantly, disposal is not merely a technical issue, but one shaped by knowledge gaps, socio-economic conditions, and absent governance mechanisms. Yet much of the literature remains focused on urban recycling streams or national-level statistics, with scant attention paid to the specific disposal behaviours and practices of rural solar users. This study responds to that gap by offering fine-grained insights into how communities manage end-of-life solar products in the absence of formal pathways.

8.2.4 Counterfeit Technologies and Solar Waste

The problem of solar e-waste in Zambia is significantly compounded by the infiltration of counterfeit and substandard solar technologies into rural markets (Munro et al., 2023a). Informal vendors often supply low-quality products that lack durability and warranty, leading to premature failure and increasing the volume of discarded equipment. Mubita and Chowa (2021) argue that counterfeit items are frequently indistinguishable from certified products, particularly for consumers with limited technical knowledge or exposure to product standards. This situation is facilitated by porous borders, weak regulatory enforcement, and inadequate testing facilities (Bates and Osibanjo, 2019). As a result, rural households are doubly burdened, first, by the economic cost of replacing failed systems, and second, by the environmental and health risks of disposing of unusable technologies. The literature largely treats these trends in isolation. This study brings these threads together by exploring the intersection of counterfeit proliferation, low literacy, and informal market dynamics as drivers of unsafe disposal.

8.2.5 Health Hazards of Solar E-Waste

The toxicity of solar waste components is well documented. Damaged PV panels and batteries can leach hazardous elements such as cadmium, lead, chromium, and arsenic, contaminating soil and water resources (Motta et al., 2016; Petroli et al., 2024). Lithium-ion batteries also pose fire and explosion hazards through thermal runaway, particularly when improperly stored or dismantled (Kumar, 2019; Usmani et al., 2020). In Zambia, awareness of these risks remains extremely low, especially in rural areas lacking education campaigns or regulatory enforcement (Munro et al., 2023a; Sinvula et al., 2021). The literature makes clear the physiological risks of e-waste exposure but offers limited exploration of how community-level awareness or lack thereof, influences actual disposal choices. This study addresses that gap by investigating how knowledge, or the absence of it, shapes household practices around solar system failure and reuse.

8.2.6 Governance Gaps in Waste Management

E-waste governance in Zambia remains nascent. Despite the exponential growth of the solar market, the country lacks a coherent regulatory framework for managing solar specific waste (Clube and Hazemba, 2024). As noted by Nalwamba (2021), existing national e-waste strategies are fragmented, urban-centric, and reactive. Attempts to move towards a circular economy are hindered by the absence of enforcement mechanisms, weak coordination among institutions, and limited incentives for private sector engagement (Chambalile et al., 2024). This institutional vacuum has been contrasted with more proactive approaches in countries like Ghana and Nigeria, where e-waste legislation has been implemented (Maphosa and Maphosa, 2020). In Zambia, however, rural communities are often left to navigate solar waste challenges on their own, without support, regulation, or infrastructure (Hansen et al., 2022; Munro et al., 2023a). This study contributes by examining how this policy void translates into grassroots experiences and coping strategies in rural settings.

8.2.7 Behaviour and Lifecycle Issues Addressed

A further issue raised in the literature is the need to consider user behaviour and product lifecycle responsibility in addressing solar e-waste (Gilal et al., 2022; Keane et al., 2024). Studies show that households frequently retain non functional solar products in the hope of repair, even in the absence of appropriate tools or services. In Zambia, Keane et al. (2024) found that nearly 89% of users stockpile defunct devices, largely due to limited disposal options and a belief in residual utility. Moreover, Munro et al. (2023b) note that many solar products are intentionally designed to be non-repairable, thereby reducing consumer agency and increasing turnover. This design logic, driven by profit motives, accelerates e-waste accumulation and disincentivises sustainable practices. Existing scholarship calls for stronger consumer education and better product design but rarely interrogates how these dynamics play out in practice, particularly in rural economies characterised by low literacy and informal governance. By focusing explicitly on the interface between user knowledge, informal reuse, and structural gaps in waste handling, this study fills a crucial empirical and theoretical gap. It adds to the body of work advocating for circularity in energy transitions by foregrounding the lived realities of solar technology end-users which are realities that remain underrepresented in policy, theory, and practice.

Taken together, the reviewed literature illustrates an emerging crisis in solar e-waste management across SSA, particularly in rural Zambia. Yet, current research often adopts a macro institutional lens, lacking nuanced accounts of how end users, informal vendors, and community structures interact with solar waste on the ground. This study addresses that void by exploring solar e-waste through the intertwined lenses of informal disposal, product quality, and literacy. It responds to the need for rural grounded, lifecycle-oriented frameworks that inform both theory and solar energy governance in low-income, off-grid contexts.

8.3 Theoretical Framework

This study applies the Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM) (Chanda et al., 2025b, 2025a, 2025c, 2025f, 2025g) (see Fig. 35) to investigate solar e-waste management within Zambia's rural energy transition. This study draws on RUDSHAM to examine the emergent solar e-waste crisis in rural Sub-Saharan Africa (SSA), with a specific focus on Zambia. Developed as a context-sensitive and integrative framework, RUDSHAM offers a multi-dimensional lens through which to analyse how socio-technical systems evolve under conditions of informality, limited literacy, and weak policy enforcement. Rather than layering several independent theories, RUDSHAM unifies key elements from existing behavioural and social models including the Technology Acceptance Model (TAM), the Theory of Planned Behaviour (TPB), Diffusion of Innovations (DOI), and Social Learning Theory

(SLT) to provide a more coherent understanding of technology use, governance gaps, and sustainability trade-offs in rural energy transitions.

In the context of solar e-waste, RUDSHAM is particularly effective in capturing how perceived ease and usefulness influence rural consumers' choices, even when those choices lead to unsafe or unsustainable disposal practices. It recognises how social norms and observational learning shape community responses to product failure, such as reusing damaged panels or accepting counterfeit goods. Further, RUDSHAM embeds structural considerations such as policy support, economic cost, and financial model suitability, enabling analysis of how macro level governance failures intersect with micro-level behaviour. The framework is especially valuable in low-literacy, decentralised settings where formal recycling infrastructure is absent, and waste management decisions are shaped by communal improvisation, misinformation, and market asymmetries.

By adopting RUDSHAM, this study moves beyond conventional adoption analysis to address the afterlife of solar technologies, a topic often neglected in clean energy discourse. It positions solar e-waste as a systemic challenge emerging from interlinked behavioural, institutional, and market dynamics. Ultimately, this theoretical lens allows for a more nuanced, contextually grounded understanding of how rural communities navigate the unintended consequences of energy transitions, thereby informing more inclusive and responsive policy interventions across SSA (see Appendices A and B).

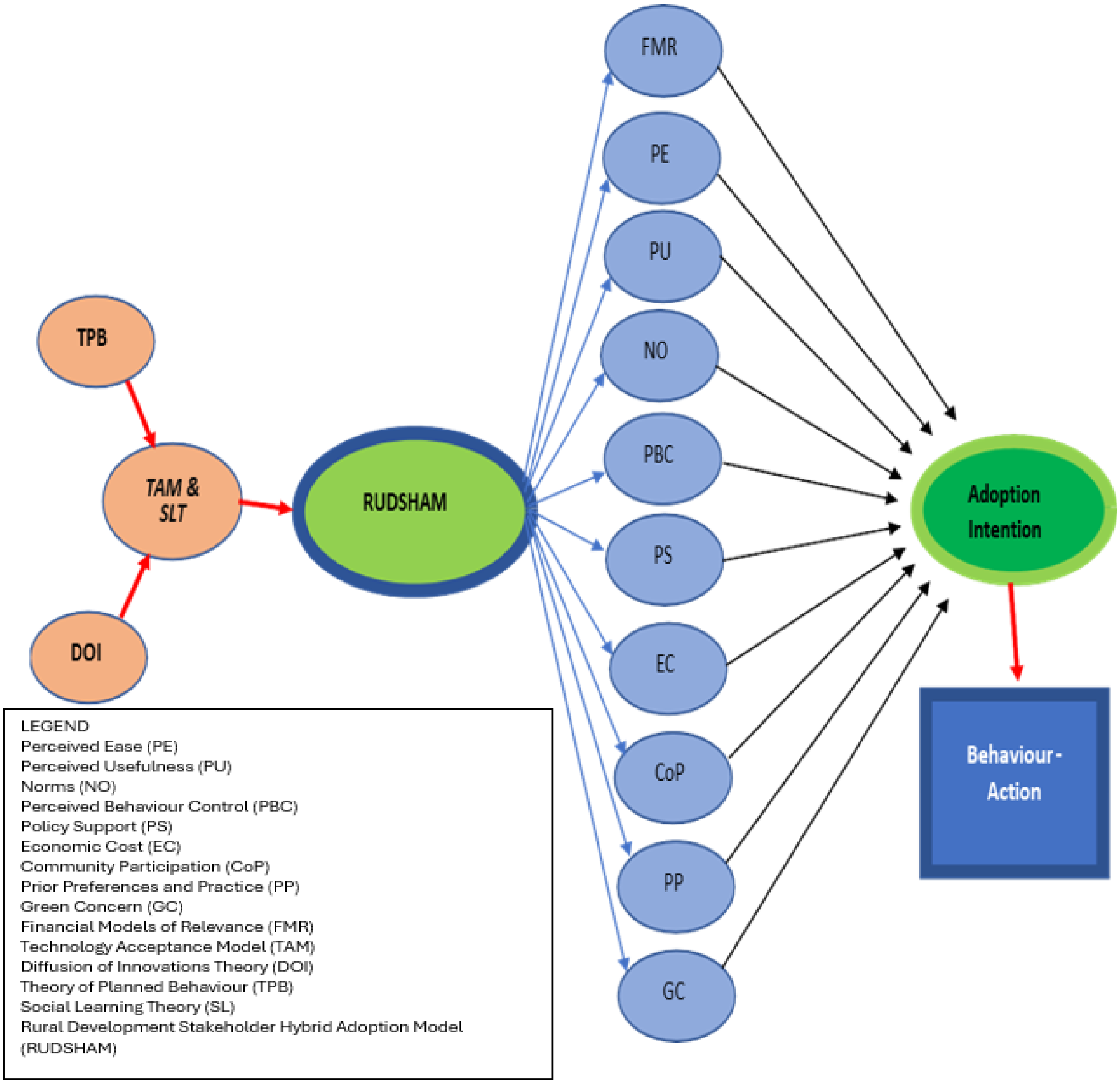

Figure 35: RUDSHAM Hybrid Adoption Model

8.4 Research Methodology

This study adopted a qualitative case study approach, underpinned by the Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM) (Chanda et al., 2025b, 2025c, 2025a, 2025f, 2025g), to investigate the multifaceted solar e-waste challenge in rural Zambia. The research specifically examined informal disposal practices, the circulation of counterfeit solar technologies, and the implications of limited literacy among users, framing these within the broader socio-technical and environmental dynamics of energy transitions in off-grid communities.

8.4.1 Study Sites and Sampling Strategy

The methodological process comprised four sequential phases: (i) site selection and stakeholder mapping, (ii) participant recruitment, (iii) primary data collection, and (iv) thematic analysis. These steps were designed to ensure contextual sensitivity, theory-guided inquiry, and rigorous data interpretation.

Fieldwork was conducted over 30-month period between October 2022 and May 2025 across four purposively selected districts: Mkushi Rural and Kapiri Rural (Central Province), Chongwe Rural (Lusaka Province), and Chingola Rural - Luano (Copperbelt Province) (see Fig. 36). These sites were selected based on their high levels of off-grid solar PV adoption, dominance of informal solar markets, and absence of formal e-waste management infrastructure. The study sites also reflect significant socio-economic vulnerabilities, limited literacy rates, and policy neglect regarding electronic waste, making them strategically relevant to the study objectives.

A multi-stage, non-probability sampling strategy was used. During the broader project fieldwork, which also included 21 interviews with charcoal burners, 40 interviews with smallholder farmers, 16 with commercial farmers, 10 FGDs and 3 with key informants from solar companies, valuable background knowledge, contextual insights, and stakeholder mappings were gathered (see Appendix C). This broader engagement enriched the research team's understanding of the local energy landscape and assisted in identifying and targeting solar PV system users for the focused study on disposal practices, counterfeits, and literacy challenges. Facilitators included local leaders and a research assistant fluent in English and several local languages (Bemba, Tonga, Soli, Lamba, and Nyanja), which enhanced participant engagement and data quality.

8.4.2 Primary Data Collection

The core data for this study were collected through 28 in-depth interviews (IDIs) and 2 focus group discussions (FGDs; see Appendix I for more details). These engagements specifically targeted rural households and businesses already using solar PV systems. The interviews probed perceptions of product quality, experiences with counterfeit technologies, disposal practices, and challenges encountered in understanding and maintaining their solar systems. The FGDs provided space for community-level validation, dialogue, and collective reflections on shared practices and risks.

The data collection process incorporated gender-sensitive approaches, ensuring balanced representation by conducting separate sessions for women and men where necessary. Interviews and FGDs were facilitated in local languages, with the assistance of trained local interpreters, ensuring inclusivity and enhancing participant comfort.

8.4.3 Data Analysis

All qualitative data were transcribed, translated, and analysed thematically using NVIVO 14. Coding was structured around the RUDSHAM framework, focusing on key dimensions of technology acceptance, counterfeit encounters, disposal behaviour, social learning, and policy awareness. The software's advanced functionalities facilitated rigorous comparison and identification of emerging patterns across participant groups. A four-week pilot phase in Luano district tested the interview and FGD guides, improving tool reliability and cultural relevance.

8.4.4 Ethical Considerations

The research adhered to ethical principles, securing informed consent from all participants. Confidentiality was maintained, and data were securely stored in encrypted folders on the University of Reading’s OneDrive platform. Modest refreshments and tokens of appreciation were provided to respect participants’ time and contributions.

Figure 36: Map of Zambia (UN 2022)

8.5 Findings

8.5.1 Counterfeits and Consumer Solar Deception

The findings in Table 37 reveal widespread reliance on counterfeit solar products due to affordability constraints, limited access to authentic products, and systemic consumer deception. Poverty drives rural users to unregulated vendors, exposing them to unsafe products. Participants express frustration at their inability to distinguish genuine from counterfeit systems, leading to economic loss and diminished trust in solar technology.

Table 37: Counterfeits and Consumer Solar Deception

#	Participant	Illustrative Direct Quotation
a	*Luano FGD 1*	*"Many of us have been cheated because we are usually unable to tell the difference between real products and counterfeits; only after using the panels are we able to find out that we were duped."*
b	*Kapiri Interview 2*	*"We rarely buy from the big shops because the solar panels there are expensive. We usually buy from unregistered vendors who go around as they are cheaper and willing to give huge discounts."*
c	*Chongwe FGD 1*	*"I bought a big solar panel from someone who came to the village. It was a dream come true, but little did I know that it was fake because it only worked for a month and packed up. I couldn't trace the seller. I have just kept the panel on the roof as a decoration...very painful."*
d	*Mkushi Interview 19*	*"Counterfeits are quite dangerous because they heat and at times smoke and burn, risking fire, especially when used for a long time."*
e	*Chongwe Interview 4*	*"Fake products are half the price or less of the original, and the discounts are usually easily given when asked but not for originals. So, the price and discounts help us to know the original or fake products."*
f	*Kapiri FGD 3*	*"The counterfeits are so similar to the originals that it's difficult to tell the difference. Sometimes they even pretend to be from original brands. Sometimes, to confuse consumers, the brand names will be similar to known brands except the spellings will be wrong."*

8.5.2 Fire Hazards from Unsafe Practices

Participants reported frequent safety hazards associated with improper use and unsafe practices, particularly 'boosting' which refers to direct battery charging without regulation, leading to fires and injuries. Ignorance, poverty, and lack of technical skills exacerbate these risks (Table 38). Unsafe disposal practices of damaged panels and batteries further endanger household members, especially children.

Table 38: Fire Hazards from Unsafe Practices

#	Participant	Direct Quotation
a	*Chongwe FGD 2*	*"When the solar panels break, sometimes people use them to make makeshift battery chargers using direct charging locally known as 'boosting' but if you leave the battery charging for a long time, it explodes violently and has been known to injure people and cause fires".*
b	*Mkushi FGD 2*	*"Fires have been reported on several occasions due to battery 'boosting' (direct charging of batteries without regulation)."*
c	*Luano FGD 2*	*"Phone batteries have caused fires but mostly they are caused due to wrong connections and bypasses, which at times emanate from ignorance. Poverty also contributes as it forces people to create dangerous battery charging shortcuts."*
d	*Kapiri Interview 13*	*"From experience, we are careful when dealing with batteries because they explode, but we don't know the other dangers associated with solar, especially chemicals and things that we can't see."*
e	*Kapiri Interview 9*	*"Some of the solar panels and bulbs are burnt, but we don't know whether exposure to the smoke of these products is harmful to health, etc."*
f	*Luano FGD 2*	*"When you get wounded from broken solar glass, the wound really takes long to heal...maybe it's because of the chemicals, so we are very careful and ensure that children are kept well away from such risks."*

8.5.3 E-Waste Disposal and Awareness Issues

The study uncovered alarming practices regarding solar waste disposal due to the absence of structured systems. Disposal methods include burying, burning, or giving panels to children, reflecting deep knowledge gaps about environmental risks (Table

39). Participants emphasised that no company or authority had provided sensitisation on the dangers of careless disposal of solar waste.

Table 39: E-Waste Disposal and Awareness Issues

#	Participant	Direct Quotation
A	*Kapiri Interview 6*	*"When the solar panels stop working, especially the cheap smaller ones, we just give them to children to play with or throw them in the pit latrine or bury them because the broken sharp pieces can injure the children."*
B	*Mkushi FGD 2*	*"Sometimes we burn or just bury the solar panels so that we safely get rid of them to protect children."*
c	*Mkushi FGD 1*	*"We have not been sensitised on how to properly and safely dispose of solar panels and solar batteries, and there is no provision for a place of disposal specifically for solar or electronic waste."*
d	*Luano Interview 3*	*"You are the first people to come and tell us about solar waste disposal; no one has ever told us about that. Companies like SunKing come to promote their systems, but they don't talk about disposal and the dangers of careless disposal."*
e	*Chongwe Interview 3*	*"We are ignorant about the dangers of solar waste because no one has cared to give us knowledge about that…so we don't know whether these things contain dangerous chemicals."*
f	*Kapiri FGD 1*	*"Many of us throw solar waste, especially broken glasses, in the toilet to ensure the children are not at risk."*

8.5.4 Low Literacy and Technical Challenges

Participants highlighted illiteracy as a critical barrier to safe and sustainable use of solar systems (Table 40). Manuals in English and the technical complexity of solar products limit their ability to understand proper usage, maintenance, and safety measures. Participants expressed the need for audio-visual, local language-based instructions and community sensitisation.

Table 40: Low Literacy and Technical Challenges

#	Participant	Direct Quotation
a	*Luano Interview 6*	*"Illiteracy is a big problem in the village, especially among us women, so we make wrong connections or have to rely on others to help us."*
b	*Luano FGD 1*	*"Instruction manuals are in English and sometimes use difficult symbols which I don't know...it makes it difficult to understand and follow the instructions."*
c	*Mkushi Interview 4*	*"I think the manuals are too detailed and difficult to read everything; hence many of us just look at the basic things and depend on explanations from others…maybe audio instructions in vernacular can work very well."*
d	*Kapiri FGD 1*	*"Knowledge dissemination and sensitisation is important for rural people using the language they understand."*
e	*Mkushi Interview 4*	*"Because of ignorance and lack of education, we are easily deceived into buying counterfeits."*
f	*Chongwe FGD 2*	*"Even reading instructions is a problem for many of us, so asking us to repair the broken panels is a tall order...additionally, the systems come sealed, so we can't open them to fix them up."*

8.5.5 Theft and Economic Vulnerability Factors

Solar technologies, particularly authentic systems, are perceived as valuable commodities, making them targets for theft and resale (Table 41). Participants reported employing security measures to protect their systems. However, counterfeits continue to be preferred despite known risks, as they remain the only affordable option in the face of poverty and systemic vulnerabilities.

Table 41: Theft and Economic Vulnerability Factors

#	Participant	Direct Quotation
a	*Mkushi FGD 1*	*"Because of poverty, original solar products are sometimes targeted and stolen and resold, although this is mostly inside jobs."*
b	*Mkushi CF Interview 4*	*"Solar panels are very desirable for local thieves. Because of theft, I have employed a watchman just to watch the solar pump system."*
c	*Chongwe Interview 3*	*"Because you have to keep buying them every now and then, counterfeits prove to be expensive in that way, but they are a short-term solution, so we have no option but to keep buying them."*
d	*Kapiri Interview 7*	*"Apart from being cheap, counterfeits also have extremely short warranty periods of maybe 3 months or less...the sellers are without fixed abode and will rarely give a brand name or contact details."*
e	*Kapiri Interview 19*	*"We are reluctant to throw the big solar panels easily, but we easily throw the smaller ones as soon as they pack."*
f	*Luano Interview 5*	*"Sometimes the parts from dismantled solar systems are used like I.Cs which are used for simple radios or fixing other things."*

8.5.6 Warranty, Brand Trust and Reliability

Trust in branded solar products is evident among participants, with experiences of longer system lifespans and reliable aftersales support from established companies (Table 42). Nevertheless, scepticism remains due to previous disappointments. Participants expressed frustrations over the lack of transparency from counterfeit sellers, who operate without warranties, fixed locations, or brand accountability.

Table 42: Warranty, Brand Trust and Reliability

#	Participant	Direct Quotation
a	*Luano FGD 2*	*"My expensive original solar panels have been working well for the past 10 years, but batteries have been giving me problems. Good quality solar panels come from brands like SunKing, MySol, Ready Pay, Fenix, MTN, TopStar etc."*
b	*Luano FGD 1*	*"SunKing even allows the buying of individual replacement parts, which is a very good thing."*
c	*Kapiri FGD 2*	*"The Chinese (counterfeit) solar systems don't come with warranty/guarantee. Many of us have bought these systems which have parked up just after a few days, and you can't be allowed to take it back."*
d	*Chongwe FGD 2*	*"Apart from being cheap, counterfeits also have extremely short warranty periods of maybe 3 months or less… additionally, the sellers are without fixed abode and will rarely give a brand name or contact details."*
e	*Luano Interview 2*	*"The reliability of the solar system is measured using length of proper function, e.g., if it lasts for 6 to 7 years or more, then it's original. Fakes last for around 2 to 3 months before starting to give major problems or even completely parking up."*
f	*Mkushi FGD 1*	*"I have had a solar lighting system from MySol for the past 9 years, but I was disappointed with RTD TV and battery which I bought and started giving me problems within a year, but they were willing to have a look."*

8.5.7 System Overload and Improper Usage

Improper use of solar systems is prevalent, with participants repurposing small systems for high-energy appliances, which shortens system lifespan and increases risk (Table 43). Misunderstandings regarding capacity and power ratings are common, revealing a critical knowledge gap that undermines the safe, sustainable utilization of solar technologies.

Table 43: System Overload and Improper Usage

#	Participant	Direct Quotation

a	*Luano interview 2*	*"We just buy solar systems that look big and attractive to the eye without much inquiry about the quality and without reading the power output."*
b	*Luano FGD 2*	*"I bought a very nice big solar system which was giving very poor output because though it was big, only a small part was effective for solar and the rest of the panel was just a decoration."*
c	*Mkushi Interview 3*	*"Some people use small solar systems meant for only lighting to power big systems like radios and TVs, and this is sometimes the problem. Hence a system meant to last 10 years ends up lasting only a few years."*
d	*Chongwe Interview 4*	*"Counterfeits display fake power ratings such that they may show a bigger output, but when you just charge a phone from the system, the power runs out and it means you won't have lights at night."*
e	*Kapiri FGD 1*	*"Because of ignorance and lack of education, we are easily deceived into buying counterfeits."*
f	*Kapiri Interview 18*	*"Many of us just look at the basic things and depend on explanations from others... maybe audio instructions in vernacular can work very well."*

8.5.8 Adaptive Solar E-Waste Reuse Strategies

To cope with the limitations of counterfeit solar products, communities employ adaptive strategies such as modifying broken systems for makeshift uses, utilizing parts for other gadgets, or repurposing solar waste into household items (Table 44). These practices underscore community resilience but also amplify environmental and safety concerns due to unregulated disposal and usage.

Table 44: Adaptive Solar E-Waste Reuse Strategies

#	Participant	Direct Quotation
a	*Kapiri Interview 15*	*"When the solar panels are broken, some clever people manage to make smaller makeshift chargers, but it's very risky, and you use them at your own peril."*
b	*Kapiri Interview 12*	*"Sometimes the parts from dismantled solar systems are used like I.Cs which are used for simple radios or fixing other things."*
c	*Luano FGD 2*	*"Damaged solar panels are normally given to kids to play around with unless they are broken, but others burn them or bury them."*
d	*Chongwe interview 1*	*"When batteries stop working, people buy them and fix the cells, but there is no such option for solar, so they are disposed of easily as they have no afterlife value."*
e	*Mkushi Interview 3*	*"We just give them to children to play with as plates or tables etc., but when broken, we throw the broken solar pieces in the pit latrine or bury them because the broken sharp pieces can injure the children."*
f	*Mkushi Interview 4*	*"Sometimes we burn or just bury the solar panels, so they safely get rid of them to protect children."*

8.5.9 Awareness of Solar Waste Hazards

Participants expressed concerns about potential health risks from solar waste but admitted to lacking definitive knowledge on the subject (Table 45). Uninformed disposal practices like burning and burying persist due to absence of education, highlighting the urgent need for targeted awareness campaigns addressing the environmental and health hazards of unsafe solar waste disposal.

Table 45: Awareness of Solar Waste Hazards

#	Participant	Direct Quotation
a	*Chongwe Interview 2*	*"We are ignorant about the dangers of solar waste because no one has cared to give us knowledge about that."*
b	*Kapiri FGD 1*	*"No solar company has sensitised us about the risks of unsafe solar panel disposal."*
c	*Luano Interview 3*	*"Some of the solar panels and bulbs are burnt, but we don't know whether exposure to the smoke of these products is harmful to health."*

d	*Mkushi FGD 1*	*"We have been told that powder which comes from energy-saving solar lamps is very dangerous to skin when injured."*
e	*Mkushi Kapiri FGD 1*	*"From experience, we are careful with dealing with batteries because they explode, but we don't know the other dangers associated with solar especially chemicals and things that we can't see."*
f	*Chongwe FGD 2*	*"We are careful with battery acid when it froths during charging because it burns skin and clothes, so we ensure that we don't touch or let the children get exposed to it."*

8.6 Discussion

The findings of this study reveal the complex, layered challenges of solar technology adoption and disposal in rural Zambia, highlighting intersections between consumer vulnerability, environmental hazards, and systemic governance gaps. While solar PV is celebrated as a cornerstone of Africa's clean energy transition, this case demonstrates how the spread of counterfeit products, unsafe repair practices, and informal e-waste handling undermine both sustainability and equity. In discussing these findings, this section situates participants' experiences within wider debates on energy justice, environmental governance, and circular economy approaches in the Global South. Each thematic area is discussed in turn, demonstrating how issues of affordability, safety, awareness, and institutional neglect converge to shape the solar e-waste challenge.

8.6.1 Consumer Deception and Accessibility Issues

The study's findings in Table 37 confirm that accessibility constraints, pervasive counterfeit proliferation, and systemic consumer deception form a critical triad affecting rural solar adoption in Zambia. Participants' accounts (8.5.1a–f) reveal how the absence of affordable, authentic solar technologies in formal markets drives rural consumers to informal, unregulated vendors who exploit these vulnerabilities through the distribution of counterfeit products at discounted prices (8.5.1b, 8.5.1e). These findings resonate with existing evidence highlighting the dominance of low-quality solar products in SSA, exacerbated by inadequate testing at borders, porous regulatory mechanisms, and limited consumer awareness (Groenewoudt et al., 2020; Mubita and Chowa, 2021). Participants detailed their inability to distinguish counterfeits from originals due to deceptive branding tactics and subtle imitation of reputable brands (8.5.1f), aligning with Hansen (2022), who reports a lack of consumer protection mechanisms in Zambia's off-grid solar market. Moreover, the health and safety implications of these counterfeit products, such as overheating, smoking, and fire risks (8.5.1d), are consistent with documented risks in Munro et al., (2023), where the sector neglects aftersales services and lifecycle responsibility, leaving users to bear the burden of systemic failures. This interplay between affordability, deception, and poor product quality reflects broader challenges documented by Nygaard et al., (2016), where rapid PV market expansion is accompanied by inequities and consumer vulnerabilities that demand urgent regulatory interventions. These findings reveal that unsafe practices are not only the result of user choices but are deeply rooted in systemic market failures. The next section explores how these vulnerabilities manifest in the form of hazardous everyday practices with direct health and safety implications.

8.6.2 Fire Hazards and Risky Practices

Building on the market-related vulnerabilities above, participants' testimonies demonstrate how inadequate access to safe technologies translates into risky improvisations during solar use and maintenance. Participant narratives in Table 38 (8.5.2a–f) reveal widespread hazardous practices associated with informal solar system repairs and battery handling. Makeshift charging techniques such as 'boosting' (8.5.2a, 8.5.2b) have become survival strategies for many rural households but are fraught with safety hazards, including violent explosions and recurring fire incidents. These observations affirm findings by Kinally et al. (2022) and Usmani (2020), who report similar patterns of unsafe battery charging and informal recycling practices in SSA, often exacerbated by poverty and lack of technical capacity (8.5.2c). Participants further expressed deep concern over the health risks associated with solar system components, particularly battery acid and broken panels. Reports of skin burns from frothing battery acid during charging (8.5.2d, 8.5.9f) and slow-healing wounds from shattered solar glass (8.5.2f) highlight direct personal and household health hazards. These reflect findings by Orisakwe et al. (2019), Sinvula, (2021) and Kinally et al. (2022), who documented severe health consequences from improper handling and disposal of e-waste, including lead-acid batteries. Additionally, the lack of awareness regarding the toxicity of smoke from burnt panels and components (8.5.2e) reveals gaps in user safety knowledge, resonating with Nalwamba (2022) on the broader neglect of health risks in Zambia's emerging solar waste discourse. Such unsafe practices point toward a deeper structural absence, the lack of organised e-waste infrastructure and awareness. The following section turns to these systemic gaps in disposal and sensitisation.

8.6.3 E-Waste Challenges and Public Awareness

From individual hazards, the discussion now shifts to the collective implications of disposal practices, situating household experiences within broader questions of environmental governance. Improper disposal practices of solar waste are prominent among participants (8.5.3a–f), ranging from burying/burning panels to using them as toys, exposing users to both environmental and health hazards (see Table 39). The testimonials expose the absence of structured e-waste disposal infrastructure (8.5.3c) and the complete lack of sensitisation by solar companies (5.3d), echoing findings by Nalwamba (2022) and Kinally et al. (2023), who identify Zambia's e-waste management system as underdeveloped and poorly enforced. Participants' limited awareness of the dangers posed by solar waste, including exposure to toxic chemicals (8.5.3e), and practices like discarding sharp fragments in pit latrines (8.5.3f), are indicative of the broader neglect of rural communities in national and corporate e-waste narratives (Lema et al., 2021). These disposal practices present serious environmental justice concerns, as communities bear the brunt of pollution in the absence of regulatory safeguards, a pattern documented by Avis (2021) and Munro et al. (2023). These systemic deficiencies cannot be separated from users' limited technical capacity and literacy levels. Accordingly, the next section highlights how knowledge gaps exacerbate unsafe practices and reinforce exclusion.

8.6.4 Capacity Gaps and Energy Sensitisation

The findings (see Table 40) on e-waste stress the centrality of human capacity. Literacy and technical knowledge emerge as critical mediators of whether solar adoption enhances well-being or produces new risks. Illiteracy and limited technical skills emerged as significant barriers to safe solar usage and disposal (8.5.4a–f). Participants' struggles to comprehend English manuals (8.5.4b, 8.5.4c) and reliance on peer explanations (8.5.4f) demonstrate the structural exclusion of low-literate populations from the off-grid solar sector's mainstream service models (Kanyamuna et al., 2021; Munro et al., 2023b). Participants advocated for localised, culturally appropriate sensitisation (8.5.4d), supporting Hansen's (2020) recommendation to integrate end-user education into renewable energy transitions, particularly in low-literacy settings. Moreover, the expressed vulnerability to deceptive sales tactics (8.5.4e) reiterates the need for consumer empowerment strategies within Zambia's off-grid solar expansion efforts, as also observed by Hansen et al. (2022). This knowledge asymmetry not only perpetuates unsafe usage and disposal but also exacerbates the environmental injustice faced by rural communities who are systematically excluded from energy justice discourses (Samarakoon et al., 2022). These capacity gaps are further complicated by how users perceive the economic and social value of solar technologies, which in turn drives new forms of vulnerability such as theft and insecurity.

8.6.5 Perceived Value and Solar Theft

Moving beyond literacy, participants' reflections illustrate how solar systems are embedded in wider livelihood strategies, with their perceived value generating both adaptive and problematic behaviours. Participants' reflections in Table 41 (8.5.5a–f) reveal that the perceived economic value of solar technologies, especially authentic products, has led to increased theft and insecurity. Households reported employing watchmen to protect solar systems (8.5.5b), while also acknowledging the cycle of repeated purchases of cheap counterfeits due to financial constraints (8.5.5c). These findings are congruent with Munro et al. (2023), who report the tension between profit-driven off-grid solar models and their limited sustainability in vulnerable communities. Participants' adaptive behaviours, such as retaining and repurposing parts from broken systems (8.5.5f), mirror findings by Kinally et al. (2023), who describe similar informal resource recovery practices in SSA, though these remain environmentally hazardous and economically unsustainable. The unwillingness to dispose of larger systems (8.5.5e), despite functional failure, reflects both sentimental attachment and the economic burden of replacement, reinforcing findings by Keane (2024), where users perceive defunct solar kits as retaining residual value. These perceptions directly shape levels of trust in solar products and suppliers. The next section explores how warranties, durability, and aftersales services affect consumer confidence and system sustainability.

8.6.6 Warranty Issues and Trust Challenges

Trust, or the lack thereof, emerges as a pivotal factor that links consumer experiences with product quality, market regulation, and long-term sustainability. Participants' narratives (8.5.6a–f) (see Table 42) revealed contrasting perceptions between counterfeit and branded solar products. While counterfeits lack warranties and quickly fail (8.5.6c, 8.5.6d), authentic systems from trusted brands were credited for their durability and customer support (8.5.6a, 8.5.6b), in line with the arguments by Munro et al. (2023) regarding the value of formal supply chains and aftersales services. However, even these brands have occasionally disappointed (8.5.6f), raising questions about the consistency of customer experiences across products and services. These findings align with Chambalile et al. (2024), who highlight the need for improved maintenance infrastructure and user support to enhance trust and system longevity. Participants' methods of assessing reliability through usage duration (8.5.6e) also highlight the lack of technical literacy, confirming earlier findings (8.5.4f) and reinforcing the call for accessible, community-level sensitisation and repair services as suggested by Hansen et al. (2020). Yet, trust is undermined not only by inconsistent warranties but also by how systems are used. The following section examines how misuse, overloading, and unrealistic expectations compound technical failures.

8.6.7 Misuse, Overloading, and System Misapplication

Beyond supply-side challenges, user practices themselves often accelerate system breakdowns, reflecting the interplay between technical limitations and consumer misperceptions. Misuse of solar systems is a recurring theme among participants (8.5.7a-f) (Table 43), where systems designed for basic lighting are routinely overloaded to power energy-intensive appliances (8.5.7c), resulting in premature failure. Participants also noted deceptive marketing of counterfeits with exaggerated power ratings (8.5.7d), leading to unmet expectations and user frustration. These practices reflect broader patterns identified by Kinally et al. (2023), where misinformation and lack of technical understanding compromise the safe application of solar technologies in rural SSA. Moreover, the prioritization of aesthetic appeal over technical specifications when purchasing systems (8.5.7a, 8.5.7b) reinforces the disconnect between user expectations and product capabilities, as also highlighted by Munro et al. (2023). Participants' reflections suggest that capacity-building interventions, such as local-language, audio-visual guides (8.5.7f), could bridge these knowledge gaps and foster safer, more sustainable solar usage, consistent with recommendations by Hansen et al. (2020) and Kinally et al. (2022). These misapplications inevitably contribute to patterns of informal reuse and premature disposal, which reveal both user ingenuity and systemic neglect of lifecycle planning.

8.6.8 Informal Reuse, Improvisation, and Disposal of Solar Components

Informal reuse and improvisation represent the community's adaptive response to structural neglect, yet they also expose users to new safety and environmental risks.

Adaptive reuse and informal disposal practices emerged as a common theme among participants (5.8a-f) (Table 44). In response to the lack of formal e-waste systems, broken solar panels are repurposed into makeshift chargers or household objects (5.8a, 5.8b, 5.8e), often without technical guidance, exposing users to electrical hazards. This informal reuse culture reflects both user ingenuity and systemic gaps in repair infrastructure, particularly in under regulated and low literacy rural contexts (Kinally et al., 2023; Munro et al., 2023a). In most cases, solar panels are either burned or buried once they become hazardous (5.8c, 5.8f), with the intent of protecting children from injury. Similar to findings by Nalwamba (2022), participants acknowledged that non-functional solar systems had little perceived afterlife value (5.8d), exacerbated by the absence of circular economy approaches and take back programmes in Zambia (Clube and Hazemba, 2024). These trends are consistent with regional patterns where poor lifecycle accountability, short product lifespans, and high repair costs drive premature disposal (Keane et al., 2024). In this context, while reuse practices reflect local adaptation, they also highlight systemic neglect in e-waste planning and signal a pressing need for policies that integrate safe reuse, repair, and recycling strategies (Chambalile et al., 2024; Kinally et al., 2023). Such improvised practices underline a critical gap, the absence of awareness and sensitisation regarding the hazards of solar waste. The final section addresses this dimension directly.

8.6.9 Limited Awareness of Solar Waste Hazards

Ultimately, participants' limited awareness of solar waste hazards encapsulates the cumulative effect of counterfeit markets, risky practices, poor infrastructure, and low literacy. Participants repeatedly highlighted the absence of formal education or sensitisation around solar e-waste hazards (8.5.9a-f) (Table 45). Respondents stated that no solar company or public agency had informed them about health or environmental risks associated with improper disposal (8.5.9a, 8.5.9b), despite common practices such as burning bulbs or handling broken battery components (8.5.9c, 8.5.9f). Awareness of specific risks, such as battery acid burns or exposure to lamp powders, tended to arise from personal experience rather than institutional knowledge (8.5.9d, 8.5.9e). These findings align with Hansen et al. (2020) and Mugendi et al. (2023), who emphasise the disproportionate burden placed on rural communities in the absence of structured e-waste education and regulatory enforcement. The limited awareness reported here mirrors broader challenges in Sub-Saharan Africa, where low literacy levels and weak infrastructure hinder risk communication (Kanyamuna et al., 2021; Kinally et al., 2023). In Zambia, the situation is compounded by a lack of solar-specific waste systems, weak policy implementation, and informal disposal habits (Munro et al., 2023a; Nalwamba, 2022). Without targeted outreach and stakeholder engagement, hazardous waste disposal behaviours may persist, undermining the environmental gains of the clean energy transition (Avis, 2021; Chambalile et al., 2024). Taken together, these findings highlight the urgent need for integrated policies that combine consumer protection, technical capacity-building, and structured e-waste management to ensure that solar energy transitions do not reproduce environmental injustice.

Taken together, the discussion reveals that Zambia's solar e-waste challenge is not a single-issue problem but the outcome of intertwined dynamics such as market deception, hazardous practices, systemic neglect, literacy barriers, and limited awareness. Addressing these requires integrated, multi-scalar interventions that safeguard consumers while strengthening environmental stewardship. The next section concludes by outlining the broader implications of these findings for policy, practice, and future research.

8.7 Policy Recommendations

This study's findings highlight the urgent need for a holistic and multi-scalar policy response to the emerging solar e-waste challenge in rural Sub-Saharan Africa. The Zambian case study reveals that while off-grid solar PV systems are expanding energy access, they are simultaneously creating new socio-environmental risks due to unregulated markets, weak consumer protections, and an absence of structured e-waste disposal systems. Addressing these challenges requires an integrated policy strategy that prioritises lifecycle responsibility, grassroots participation, and inter-sectoral collaboration.

A key entry point for reform is solar import regulation and consumer protection. The proliferation of counterfeit products stresses the necessity for enhanced border control mechanisms. Institutions such as the Zambia Bureau of Standards (ZABS), Zambia Revenue Authority (ZRA), and Zambia Compulsory Standards Agency (ZCSA) must establish testing and certification systems at major entry points to screen imported solar technologies. Simultaneously, the Ministry of Commerce, Trade and Industry (MCTI) should strengthen the regulation of informal solar markets, with support from civil society organisations like the Zambia Consumer Association (ZACA) and Consumer Unity & Trust Society (CUTS Zambia). These actors can lead public education efforts focused on product authenticity and consumer rights, while empowering rural users to demand quality. Equally vital is the formulation of a national solar e-waste policy tailored to the off-grid energy sector. The Ministry of Green Economy and Environment (MoGEE), in partnership with the Zambia Environmental Management Agency (ZEMA), should spearhead the development of a dedicated framework that addresses the unique waste streams of solar PV systems. This policy must ensure that decentralised regions are not excluded; take back schemes, recycling centres, and mobile collection units should be piloted in rural districts. Collaboration with international partners like SolarAid, IRENA, and GIZ Zambia can bring technical expertise and help operationalise pilot models grounded in local realities.

Addressing the knowledge gap among end-users is critical. The study found widespread limitations in system understanding, disposal awareness, and maintenance skills. A unified Community Education and Awareness strategy is thus essential. The Ministry of Energy (MoE), Ministry of General Education (MoGE), and Rural Electrification Authority (REA) should jointly develop national energy literacy campaigns. These initiatives should integrate information on safe solar use, counterfeit risks, and disposal hazards into culturally adapted, multilingual formats, leveraging community radio, faith-based platforms, and traditional leaders for wider dissemination. Furthermore, the Energy Regulation Board (ERB) should require all licensed solar vendors to provide standardised end-user education materials as part of their compliance obligations. The policy framework must also address the structural vulnerabilities of the informal solar market. The Ministry of Small and Medium Enterprises Development (MSMED), in collaboration with UNCDF and local microfinance institutions, should support the formalisation of rural solar enterprises. This could include microcredit schemes for certified vendors, tax incentives for quality compliant distributors, and support for decentralised repair hubs. Empowering local entrepreneurs and cooperatives in this way will promote sustainable, locally embedded energy economies, and reduce reliance on exploitative or low-quality supply chains.

To foster durability and trust in solar technologies, product design and aftersales service require policy attention. The ERB should enforce warranty and repair obligations, encouraging providers to adopt modular and repairable designs suited for rural conditions. Public-private partnerships with NGOs like Practical Action and private sector actors can support the establishment of local service centres and technician training schemes. These measures would mitigate safety risks linked to poor system handling while extending product lifespan and user satisfaction. In tandem, safe solar reuse and refurbishment pathways must be promoted. Informal repurposing is often a survival strategy in rural Zambia but carries environmental and health risks. The Ministry of Green Economy and ZEMA should introduce clear national guidelines on reuse, working alongside solar associations to pilot safe repurposing workshops. Investment in second-life product innovation, backed by partners such as UNDP or GIZ, can reduce premature disposal and support circular economy principles in marginalised areas.

Lastly, a cross-cutting issue is the lack of public knowledge about e-waste hazards. The Ministry of Health and REA should co-lead targeted e-waste hazard awareness campaigns, integrating these into public health messages and school curricula. Solar vendors should be required to provide clear disposal instructions, and community health workers can serve as frontline educators. Ensuring basic e-waste literacy will empower rural communities to manage solar waste safely and protect both environmental and human health. This study advocates for an integrated governance approach to solar e-waste, where product regulation, education, infrastructure, and market reform are pursued simultaneously. Such a strategy is essential to achieving Sustainable Development Goal 7 in a manner that is just, inclusive, and ecologically sound.

8.8 Conclusion

The rapid expansion of off-grid solar in Sub-Saharan Africa has been celebrated as a pathway to bridging energy access gaps, yet this study demonstrates that such transitions are also accompanied by unintended consequences that are often overlooked in policy and scholarship. Drawing on qualitative evidence from rural Zambia, the research illuminates how the proliferation of counterfeit technologies, unsafe disposal practices, and low literacy converge to produce a mounting solar e-waste challenge. This conclusion synthesises the study's key findings, highlights its contributions to knowledge, outlines future research trajectories, acknowledges limitations, and reflects on broader implications for just and sustainable energy transitions.

The study critically examined the emerging solar e-waste challenge in rural Zambia, highlighting the interplay between informal disposal practices, the influx of counterfeit solar technologies, and the implications of low literacy levels. The findings reveal that rural communities predominantly engage in unsafe disposal methods, burning, burying, or repurposing solar components, without awareness of the associated environmental and health risks. The proliferation of counterfeit technologies, often indistinguishable from authentic brands, has further intensified the accumulation of dysfunctional solar products. The study also established that low literacy and limited technical capacity exacerbate unsafe behaviours and obstruct users from engaging with safe disposal practices or understanding product warranties and maintenance requirements. These issues are compounded by the absence of formal e-waste management infrastructure, regulatory deficits, and weak enforcement, positioning solar e-waste as an urgent, yet overlooked, environmental justice issue within Zambia's clen energy transition. Building on these findings, the study contributes new empirical and theoretical insights that advance academic and policy debates on energy transitions in the Global South. By adopting the Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM), the study moves beyond purely technical or market-centric analyses, presenting a holistic understanding of the socio-technical, behavioural, and governance dynamics shaping rural solar e-waste challenges. In doing so, the research extends the discourse on energy justice, technology misuse, and consumer vulnerability within off-grid solar adoption narratives, providing actionable insights for sustainable energy transitions that are both inclusive and context-sensitive. It also identifies critical gaps in the current renewable energy governance frameworks that neglect end-of-life solar system considerations, thereby enriching applied energy scholarship with interdisciplinary perspectives on technology justice and environmental health.

While these contributions are significant, they also open avenues for further inquiry into the evolving landscape of solar e-waste in rural contexts. The complexities identified in this study suggest several pathways for further inquiry. Longitudinal, cross-seasonal research is necessary to explore how disposal behaviours and system misuse fluctuate with agricultural cycles, income variability, and seasonal weather patterns. Further studies should also investigate the economic and cultural logics underpinning consumers' acceptance of counterfeits and informal markets, employing participatory and ethnographic methods to deepen understanding of user perspectives. Additionally, action research examining the efficacy of localised, culturally tailored solar literacy interventions could provide valuable lessons for integrating energy-waste education into broader rural development strategies. While future research can deepen and expand the scope of these findings, it is equally important to acknowledge the limitations of the present study. The study was conducted over a relatively short fieldwork period, and as such, seasonal variations in disposal practices, income streams, and solar system utilisation may not have been fully captured. Future research employing year-round monitoring would be instrumental in unpacking these temporal dynamics. Moreover, the study's focus on specific districts may limit generalizability; however, the selected sites' strategic relevance offers critical insights into contexts where informal solar markets, policy neglect, and socio-economic vulnerabilities converge.

Despite these limitations, the study provides compelling evidence that can inform both academic discourse and policy reform. It highlights the dual-edged nature of off-grid solar PV diffusion in rural Zambia. While it aligns with Sustainable Development Goal 7 by improving access to clean and affordable energy, it simultaneously reveals a range of unintended socio-environmental consequences. Counterfeit technologies, limited consumer literacy, and the absence of structured e-waste disposal mechanisms pose significant risks to both human and ecological well-being. These findings suggest that achieving SDG 7 in rural Sub-Saharan Africa requires more than expanding energy access, it necessitates embedding principles of equity, environmental stewardship, and institutional accountability throughout the technology lifecycle. The research contributes to the growing literature on just energy transitions by advocating for user-centred, locally contextualised governance frameworks. Addressing solar e-waste through participatory policy mechanisms and targeted capacity building will be critical in preventing the marginalisation of vulnerable groups. Overall, the study calls for holistic, anticipatory planning to ensure that energy transitions are not only accelerated, but also inclusive, ethical, and sustainable.

Chapter 9: Exploring the nexus of solar adoption, sustainability, and rural community development through the role of white commercial farmers: The case of Mkushi, Zambia. (Article 5)

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Summary: This article investigates the role of White commercial farmers (WCFs) in shaping decentralised solar photovoltaic (PV) adoption and rural development in Zambia, focusing on the Mkushi farming block. Recognising that rural electrification strategies often overlook non-traditional actors, the study examines how WCFs contribute to rural energy transitions not only as private adopters but also as informal financiers, conservation stewards, and facilitators of community development.

Abstract: Key findings indicate that WCFs actively support energy access in surrounding off-grid communities by enabling informal leasing of solar equipment, co-funding rural infrastructure, and promoting conservation-sensitive agriculture. They also serve as intermediaries between rural populations, development agencies, and government institutions. However, these contributions are constrained by policy fragmentation, affordability barriers, and limited government coordination, which leave WCF efforts largely unrecognised and under leveraged at the national level.

Recommendations: The study recommends integrating WCFs into Zambia's formal rural energy policy through structured public-private partnerships. Specific measures include incentivising land and infrastructure sharing for community mini-grids, co-designing rural energy security mechanisms, and linking solar deployment with conservation compliance frameworks. A participatory governance approach is also advocated to address potential power asymmetries and foster collaborative planning.

Overall contribution: This article directly addresses Thesis Objective 4 by investigating the contributions of unconventional actors to decentralised energy access. It adds an institutional and equity-oriented dimension to the thesis by expanding the analytical scope beyond households to include agrarian elites and their embedded roles in community infrastructure and sustainability transitions.

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9.1 Introduction

Access to clean, affordable, and reliable energy remains a persistent development challenge across sub-Saharan Africa (SSA), where over 600 million people lack electricity (Chanda et al., 2025a; M. M. Santos et al., 2023). In Zambia, only 25% (less than 6% for rural areas) of the population has access to electricity and clean cooking facilities, despite the country's significant solar potential (Chanda et al., 2025a; ERB, 2024; MOE, 2024; M. M. Santos et al., 2023; ZESCO, 2024a). Current power deficit, which is partly climate induced, stands at 594MW for Zambia. Production is 1,806MW, of which about 3.23% is solar, against 2400MW demand on average. Decentralised solar photovoltaic (PV) technologies, such as mini-grids and standalone systems, are widely recognised as key solutions for rural electrification (Stritzke and Jain, 2021). Yet, their adoption remains constrained by high costs, limited technical capacity, inadequate infrastructure, and underdeveloped markets (Chambalile et al., 2024). Most initiatives are led by governments, NGOs, or international donors, while the role of other local actors, particularly White commercial farmers, has received limited scholarly attention.

This study explores the underexamined role of White commercial farmers (WCFs) in facilitating solar PV adoption, promoting environmental sustainability, and supporting community development in Zambia's Mkushi farming block. Located in the Central Province, the Mkushi block spans 176,000 hectares and was originally designated in the 1950s by the colonial government for European tobacco farmers, particularly ex-servicemen (Matenga and Hichaambwa, 2017). Today, Mkushi remains a prominent site for large-scale agriculture, predominantly owned and operated by WCFs (Matenga, 2017). These farmers hold a distinctive position in Zambia's rural socio-economic landscape, not only as agricultural producers, but also as landowners, employers, and providers of critical infrastructure in otherwise underserved areas. Their influence extends beyond formal farming operations to include informal contributions to rural services, local employment, and, in some cases, decentralised energy access.

The relationship between WCFs and their surrounding rural communities is complex yet interdependent. While smallholder farmers and local households often rely on these farms for jobs, services, and infrastructure, the farmers themselves depend on local labour, land access, and community cooperation. This symbiotic dynamic, if strategically harnessed, could serve as a foundation for collaborative investments in solar PV infrastructure and broader sustainability initiatives. However, there is little empirical evidence on how these farmers engage, directly or indirectly, in energy transitions or in supporting rural community sustainable development. The aim of this chapter is to investigate whether, and in what ways, WCFs in Mkushi contribute to the adoption of solar PV technologies, sustainability, and community development in surrounding rural areas.

The study has three main objectives:

- To assess the nature and extent of White commercial farmers' engagement in off-grid solar energy transitions within the Mkushi block, and their potential role in Zambia's decentralised energy strategy.
- To examine the impact of White commercial farmers on rural livelihoods, equity, and social outcomes in nearby communities.
- To explore their contributions to local environmental sustainability and conservation practices.

In Zambia's context of limited state capacity, understanding how commercial farmers operate as informal development agents may offer insights into hybrid governance models that integrate private actors into public energy and sustainability agendas. This research contributes to an emerging literature that foregrounds the social, institutional, and relational dimensions of energy transitions, moving beyond purely technical solutions to consider the actors who shape them (Nyoh, 2021).

9.2 Literature Review

The literature on solar energy adoption in Sub-Saharan Africa has often focused on state actors, NGOs, and end-user households, but less attention has been given to meso-level actors like commercial farmers who interface directly with both technology suppliers and rural communities. This review therefore synthesises the role of White commercial farmers (WCFs) across five thematic areas, laying the foundation for understanding their influence on solar diffusion, sustainability, and rural development.

9.2.1 Informal Solar Use by White Commercial Farmers

White commercial farmers are largely absent in scholarly and policy discussions around solar energy transitions in Zambia. However, their position as rural infrastructure providers and economic anchors makes them potentially influential actors in informal energy governance (Naumann and Rudolph, 2020). In contexts where formal energy access is limited, WCFs could act as entry points for off-grid solar PV deployment, especially if they invest in technologies like solar water pumps or cold storage systems (Mwanza et al., 2017). Yet empirical studies focusing on the contributions of WCFs to energy transitions remain sparse. This is despite growing recognition that exogenous actors, such as commercial landholders, can support niche energy innovations and influence national policy regimes (Dong and Mori, 2017). In Zambia, which struggles with rural energy access (Chanda et al., 2025a, 2025b), WCFs may bridge the access gap through demonstration effects or partnerships with local communities. Moreover, WCFs often operate beyond the purview of formal electrification efforts, making their energy decisions both autonomous and impactful in rural off-grid areas. Their embeddedness within agro-industrial systems offers a valuable yet underexamined lens for assessing decentralised solar energy transitions.

9.2.2 Community Development in Farming Zones

The socio-economic effects of commercial farming on surrounding communities are multifaceted. In Mkushi, WCFs have created employment opportunities but have also been associated with casual labour practices and low wages (Matenga, 2017). Mechanization and precision farming have displaced traditional jobs, creating a labour-supply paradox: demand for specialised labour coexists with underemployment of local populations (Nolte and Subakanya, 2016). While out-grower schemes to induce specific crop production by smallholders have shown potential for asset accumulation (Matenga, 2017), issues such as gendered income disparities and elite capture persist. Moreover, these dynamics are complicated by land governance challenges; even when investments occur on state land, dissatisfaction often arises due to opaque land acquiring processes and unequal power dynamics (Nolte and Subakanya, 2016). As community development increasingly intersects with energy transitions, the importance of transparent and participatory approaches becomes more salient (Chileshe, 2023a). If appropriately engaged, WCFs could contribute to community-based solar governance models that address social equity alongside energy access. Such collaboration could reposition farmers not just as economic agents, but also as social intermediaries linking energy providers and local institutions. Additionally, existing community-based structures, such as farmer cooperatives, could be leveraged to scale off-grid solar adoption through shared infrastructure or pooled financing.

9.2.3 Sustainability in Commercial Agriculture Sector

WCFs also have a potentially transformative role in promoting environmental sustainability. Large farms are significant consumers of water and energy, and their practices can either degrade or conserve ecosystem functioning. Hybrid energy systems integrating solar, wind, and biogas offer promising options for sustainable farm operations (Tambatamba and Kumwenda, 2018), yet there is limited documentation on WCF adoption of such technologies. Conservation agriculture models like Pfumvudza, focused on minimum tillage and crop rotation, demonstrate strong environmental benefits (Mavesere and Dzawanda, 2023). However, these approaches also pose socio-economic concerns, such as labour intensiveness and gendered workloads (Bhatasara et al., 2025; Tanyanyiwa et al., 2022). WCFs, given their access to mechanised technologies, could support adaptation and scaling of such models, reducing the physical burden on labourers and integrating conservation with productivity. Additionally, their capital-intensive operations may enable early adoption of cleaner technologies, which can later be replicated in smallholder systems. Their participation could also generate vital data on the performance of sustainable practices under local conditions, contributing to region specific innovations.

9.2.4 Agricultural Spillovers and Rural Livelihoods

Commercial agriculture has shown the potential to catalyse rural development through knowledge and technology transfer. In Nigeria, white Zimbabwean farmers improved local productivity through the dissemination of high-input practices (Adewumi et al., 2013), though tensions over land rights and exclusionary dynamics emerged (Batisai and Mudimu, 2021). In Zambia, proximity to large farms has been associated with increased cultivation among smallholders, but not with improved input access (Hicks and Ison, 2018). Similar patterns are observed in community integration models, where outgrower schemes create differentiated outcomes depending on implementation design and household structure (Matenga and Hichaambwa, 2017). These insights suggest that rural development outcomes depend heavily on how commercial agriculture interfaces with local governance, land rights, and institutional arrangements (Chu, 2013). WCFs are thus uniquely positioned to foster productive spillovers if institutional bottlenecks are addressed and engagement is guided by inclusive frameworks. Moreover, solar technology diffusion could benefit from these agricultural networks, particularly in enhancing productive use of energy at household and enterprise levels.

9.2.5 Corporate Social Responsibility and Local Engagement

Evidence from Zambia's mining sector illustrates that the success of corporate-led development initiatives hinges on early community engagement, trust-building, and realistic expectations (Mondoloka, 2017). WCFs, occupying similar positions in rural geographies, must navigate these relational dynamics to avoid enclave outcomes and foster co-development (Nolte and Subakanya, 2016). Mechanisms such as participatory energy planning, co-financing of SHS, or infrastructure-sharing could align WCFs' interests with those of their surrounding communities.

The reviewed literature reveals that WCFs in Zambia, and particularly in Mkushi, possess considerable latent potential to advance solar PV adoption, sustainability, and rural development. Their influence stems not only from their economic power and infrastructural reach but also from their embeddedness within local socio-ecological systems. However, their contributions remain understudied, and their engagement largely informal. Addressing these gaps requires empirical research that situates WCFs as strategic actors within Zambia's decentralised energy landscape, while critically evaluating the social and environmental implications of their involvement. This study aims to contribute to this nascent field by exploring the interplay of energy, equity, and development through the lens of commercial agriculture in Mkushi. Integrating CSR with energy access initiatives could shift WCF engagement from ad hoc philanthropy to structured rural development models. As energy justice and decentralisation gain traction in SSA policy discourse, WCFs represent an important but overlooked stakeholder group for inclusive energy transitions.

9.3 Theoretical Framework

To interrogate the role of WCFs in solar PV adoption, community development, and environmental sustainability in Mkushi, Zambia, this study applies the Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM) (Chanda et al., 2025a, 2025b, 2025c) (see Fig. 37). RUDSHAM offers an integrated, multi-theoretical framework to explore how rural actors, both formal and informal, navigate intersecting pressures of economic survival, energy access, and environmental conservation. In a context where public services are limited and commercial agriculture dominates, the framework is uniquely suited to unpack the uneven dynamics of rural development and energy transitions in Zambia.

RUDSHAM blends behavioural, structural, and ecological perspectives, drawing upon four foundational theories: the Technology Acceptance Model (TAM) (Davis and Davis, 1989; Venkatesh and Davis, 2000), Diffusion of Innovations (DOI) (Rogers, 2003b; Turner, 2007), the Theory of Planned Behaviour (TPB) (Ajzen, 1991), and Social Learning Theory (SLT) (Bandura, 1977). These are integrated with broader policy, economic, and environmental variables to assess how actors such as WCFs influence or impede equitable solar adoption and sustainability. TAM informs how WCFs and surrounding households interpret the usefulness and cost-benefit of solar technologies. In the Mkushi context, WCFs may adopt solar for irrigation or agro-processing, while rural households might prioritise it for essential services such as lighting and charging. The distinction between commercial and domestic motivations highlights the divergent perceptions of utility. Often, short-term financial logics overshadow environmental considerations, particularly where investment risk is high or energy markets are unstable.

DOI helps illuminate the spread of solar innovations within rural systems. As early adopters with economic capital and infrastructural resources, WCFs can play a catalytic role in disseminating new technologies across local networks. Turner (2007) and Rogers (2003) suggest that diffusion occurs not merely through access, but through visibility, influence, and trust (Chanda et al., 2025a). WCF led installations, when visible to labourers, local suppliers, or outgrower scheme participants, may act as informal demonstration projects, promoting wider uptake through observational learning and imitation.

TPB provides a mechanism to analyse the behavioural intentions behind solar PV adoption. The attitudes of WCFs toward sustainability, perceived social obligations, and perceived behavioural control (e.g., financial liquidity, regulatory clarity) all contribute to the decision to invest in off-grid energy. Similarly, the aspirations and constraints experienced by rural households are shaped by socio-cultural expectations, economic dependency, and perceived legitimacy of solar systems installed on commercial farms.

RUDSHAM's inclusion of SLT further embeds individual energy decisions in collective social contexts. In rural Zambia, energy and technology choices are often influenced by peer practices and community norms (Bandura, 1977). If local residents observe WCFs powering irrigation systems or storing perishable goods with solar cooling, such practices may gain symbolic and practical legitimacy. This visibility effect, however, can also reinforce inequalities if WCFs adopt advanced systems that remain inaccessible to poorer households.

Where RUDSHAM departs from conventional behavioural models is in its explicit ability to analyse governance, market failures, and ecological trade-offs among other things. In Zambia's weakly institutionalised energy landscape, policy ambiguities and lack of affordable financing mechanisms constrain rural electrification. The framework enables analysis of how WCFs operate in this vacuum, either as gap fillers or gatekeepers. Their capacity to finance private solar systems or co-invest in local initiatives may accelerate decentralised energy access, but their priorities may not align with inclusive or sustainable development. Furthermore, the framework supports exploration of sustainability trade-offs. In resource-scarce contexts, households may sell charcoal or timber to purchase solar kits, creating a paradox where clean energy uptake coexists with forest degradation. While the Clean Energy - Deforestation Paradox is typically applied to household dynamics, RUDSHAM allows its extension to WCFs who may promote conservation agriculture while indirectly contributing to land pressure through expansionist practices or mechanization.

RUDSHAM's analytical versatility permits the study to evaluate how WCFs' influence manifests across interconnected domains of energy, livelihoods, and the environment. It situates solar PV adoption not simply as a technological choice, but as a socially and ecologically embedded process shaped by visible power asymmetries, institutional fragility, and contested rural development trajectories. For details of how each attribute of the RUDSHAM framework assisted see Appendix B.

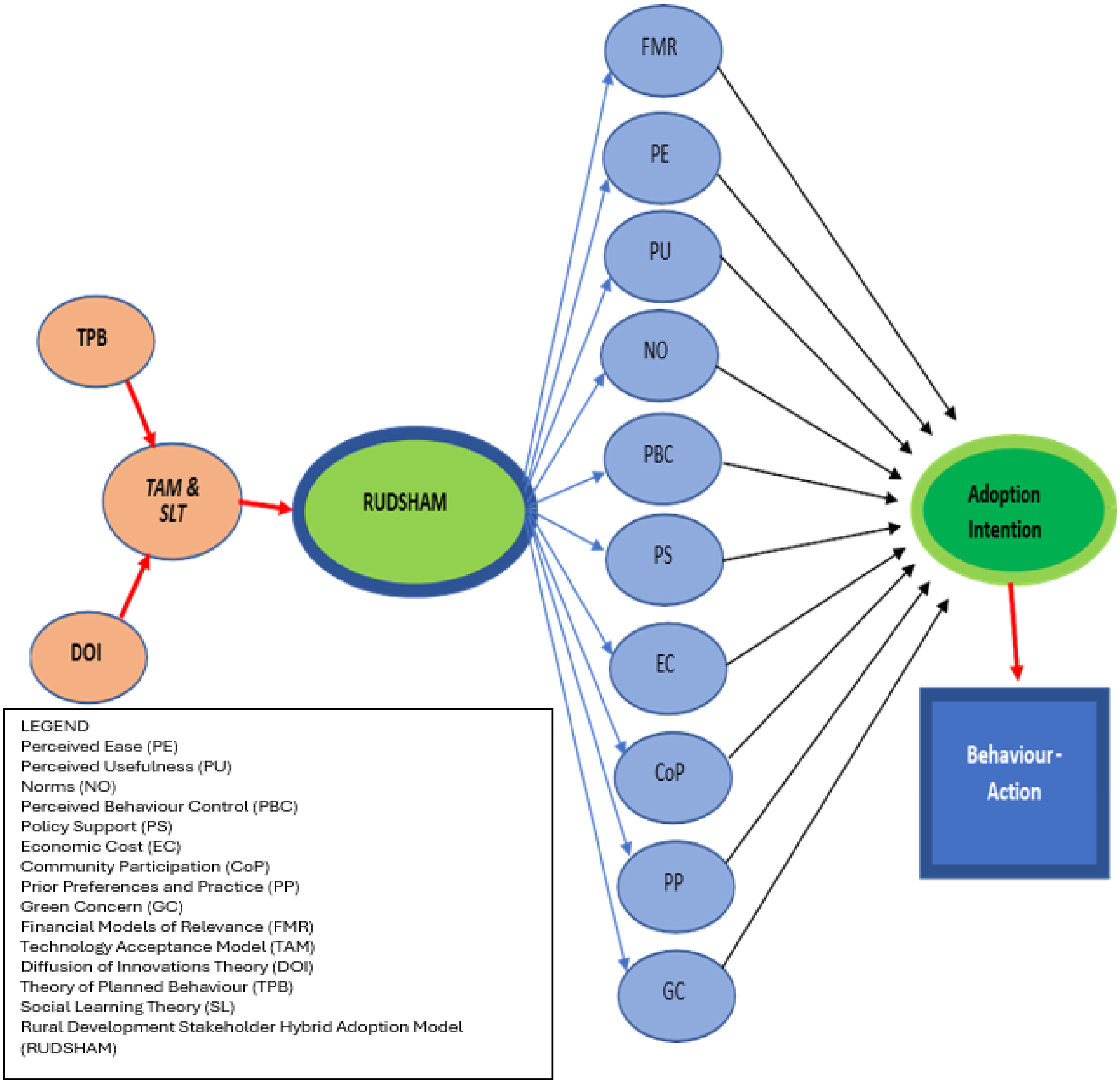

Figure 37: RUDSHAM Hybrid Adoption Model

9.4 Research Methodology

This study employed a qualitative case study design, grounded in the Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM) (Chanda et al., 2025b, 2025a, 2025c), to critically examine the contributions of White commercial farmers to solar PV adoption, environmental sustainability, and community development in Mkushi, Zambia. RUDSHAM's integrative framework facilitated a multi-dimensional exploration of socio-technical transitions in rural energy, with attention to behavioural, institutional, and environmental dynamics.

The RUDSHAM guided methodology enabled an investigation into how socio-economic positionality, perceived utility, community influence, and governance structures converge to shape energy adoption processes. By drawing from the framework's ten theoretical and contextual attributes (see Appendix B), the study identified intersecting influences on solar PV uptake among commercial and smallholder actors. This analytical breadth provided an enriched perspective on how commercial farming operations, particularly those run by white settler descendant farmers, affect rural electrification and sustainability transitions.

Data was collected over a six-month period from October 2022 to March 2023 in Mkushi district in Central Province of Zambia (see Fig. 38). The site was purposefully selected based on its geographical isolation, presence of large-scale commercial agricultural operations and limited access to the national electricity grid among the surrounding rural community. Prior to the main study, a four-week pilot was conducted with five participants in Luano village (Chingola Rural, Copperbelt Province) to refine the research instruments and protocols. Feedback from this pilot informed minor modifications to the interview guide and focus group procedures, enhancing validity and contextual sensitivity. A local research assistant proficient in English and multiple indigenous languages (Bemba, Tonga, Soli, Lamba, and Nyanja) supported data collection. The principal investigator, with fluency in English and working knowledge of Bemba, Nyanja, and Lamba, provided additional linguistic and cultural mediation during interviews and focus groups. Data collection comprised 16 in-depth semi-structured interviews (see Appendix C) with White commercial farmers, 1 focus group discussion and 3 interviews with key stakeholders from the energy sector and government policy institutions.

All interviews and FGDs were recorded with prior informed consent. Digital files, including audio recordings and consented photographs, were securely stored on the University of Reading's OneDrive cloud platform, with access restricted to the research team. Data were analysed thematically using NVIVO 14 software and colour coding. Interview transcripts were coded based on emergent themes and mapped against the RUDSHAM framework to identify cross-cutting patterns related to solar energy adoption, livelihood outcomes, and ecological stewardship. Quotations were extracted to support key findings and enhance narrative authenticity. The research adhered strictly to ethical protocols and received prior ethics approval from the University of Reading's ethics committee (see Appendix J). Participants were fully briefed on the study objectives, data confidentiality, and their right to withdraw at any point. Written and oral informed consent was obtained, and data handling procedures complied with international standards for research ethics and data protection.

By integrating the RUDSHAM framework into a methodologically rigorous, context-specific qualitative framework, this study offers empirically grounded insights into the socio-political ecology of solar PV adoption in rural Zambia. It provides a foundation for developing policy interventions that recognise the hybrid governance role of White commercial farmers in off-grid energy transitions. However, the focus on only White commercial farmers for data collection and relatively short time duration emerged as limitations.

Figure 38 Map of Zambia (UN 2022)

9.5 Findings

9.5.1 Community Engagement & Development

The findings in Table 46 indicate that White commercial farmers (WCFs) function as de facto providers of public goods, actively engaging in community infrastructure, education, health, and spiritual support. Their efforts are institutionally coordinated through mechanisms like the Mkushi Farmers Association, reflecting a participatory model of rural development grounded in mutual respect and co-contribution. This theme was explored under the Community Participation (CoP) and Policy Support (PS) dimensions of RUDSHAM, enabling a focused assessment of community ownership and stakeholder collaboration.

Table 46: Community Engagement & Development

#	Participant	Direct Quotation
a	*Mkushi CF Interview 1*	*"The relationship with the surrounding community is friendly."*
b	*Mkushi CF Interview 9*	*"I have such a good relationship with the surrounding community… they brought the gates back… (laughs)."*
c	*Mkushi CF Interview 1*	*"There are lots of projects I know—like primary schools, clinics, etc. Commercial farmers (CFs) are involved in the community."*
d	*Mkushi CF Interview 1*	*"Sadly, a senior government official...said Mkushi commercial farmers do nothing for the community... He apologised when he saw the magnitude of our community efforts."*

e	*Mkushi CF Interview 1*	*"As Mkushi Farmers Association (MFA), we ensure that our aid reaches the intended rural community recipients..."*
f	*Mkushi CF Interview 4*	*"The Mkushi Farmers Association (MFA) gets a levy from each farm depending on farm size, to raise funds to help schools, clinics, churches, individuals, and traditional ceremonies, etc."*
g	*Mkushi CF Interview 4*	*"When we do community projects, we ensure that the community also contributes to build a sense of ownership."*
h	*Mkushi CF Interview 6*	*"Handouts don't work. I don't give things for free but ensure that the rural community contributes to encourage a sense of ownership."*
i	*Mkushi CF Interview 2*	*"Many farmers have built clinics and schools on their farms. I know of a farmer who has a clinic, school, shop, and church at his farm. It's self-contained."*
j	*Mkushi CF Interview 9*	*"My neighbour has a school, a clinic, and is building houses…"*
k	*Mkushi CF Interview 6*	*"We have a school on our farm, which I built 16 years ago… sadly, they stole the doors to the school a day before it was opened… (laughs)."*
l	*Mkushi CF Interview 2*	*"Chengelo International School, an initiative of CFs, has its own community service programme, which has built some classroom blocks in the surrounding community area."*
m	*Mkushi CF Interview 2*	*"CFs organised funds to provide a loan for the church to buy a soya expressing machine."*
n	*Mkushi CF Interview 2*	*"Currently, with the assistance of CFs, the block has 26 local language churches and 2 English churches... fostered positive moral change..."*
o	*Mkushi CF Interview 2*	*"As CFs, we built a house for a missionary... linked up with an NGO called World Servants... The teams come twice or thrice a year."*
p	*Mkushi CF Interview 10*	*"We work with Dutch volunteers who have helped with various projects…"*
q	*Mkushi CF Interview 2*	*"The CFs have also formed an orphanage and an after-school feeding programme and homework club..."*
r	*Mkushi CF Interview 6*	*"In the Mkushi farming block, 25 information centres for rural farmers have been resuscitated by CFs…"*
s	*Mkushi CF Interview 6*	*"There are many acts of kindness that CFs do in the community… hospital bills… they keep a low profile."*

9.5.2 Energy Access & Affordability

Data in Table 47 reveals that while rural demand for solar energy is high, affordability remains a major constraint. White commercial farmers offer informal support by providing land, infrastructure, and wage deduction schemes for solar purchases. However, their facilitative role is limited by policy inefficiencies, high costs, and an inability to access grid markets. Several also expressed a desire for feed-in tariffs that could help cover the cost of the PV investment. The RUDSHAM attributes of Economic Cost (EC), Perceived Usefulness (PU), and Policy Support (PS) informed our analysis by illuminating key financial and infrastructural barriers to solar adoption.

Table 47: Energy Access & Affordability

#	Participant	Direct Quotation
a	*Mkushi CF Interview 12*	*"So many solar systems are entering the rural places because people appreciate them."*
b	*Mkushi CF Interview 8*	*"Beyond lighting and charging phones, productive solar use is prohibited by cost…"*
c	*Mkushi CF Interview 2*	*"Because batteries are prohibitively expensive for rural people, I would recommend that they only use solar during the day when the sun is out… especially for productive purposes."*
d	*Mkushi CF Interview 3*	*"I would be willing to deduct money from my employees' salaries if solar companies provided pay-slow models."*
e	*Mkushi CF Interview 2*	*"I have encouraged my gardener from the rural community and supported him to use solar for lighting his poultry business, his home, and for charging his phone, etc."*
f	*Mkushi CF Interview 2*	*"I suggest that to help the rural people, the government can make community farms for the rural people, and the proceeds used for solar or biogas promotion."*
g	*Mkushi CF Interview 1*	*"Government should consider widespread solar grids in remote places and offer incentives to the private sector or partner with national and international organisations..."*

h	*Mkushi CF Interview 1*	*"I am willing to offer land for a solar plant and to host and manage it, provided it can also feed into the grid."*
i	*Mkushi CF Interview 4*	*"I am willing to host a solar farm, but I need to have the ability to sell power to ZESCO."*

9.5.3 Governance, Policy & Institutional Support

The research demonstrates that WCFs often substitute for weak state institutions by funding security, healthcare, and infrastructure (Table 48). Although some collaboration with traditional leaders and NGOs exists, systemic fragmentation and lack of public-private integration hinder their impact. Calls for policy reform, including reduced electricity grid connection charges (i.e., wheeling costs), remain urgent and unresolved. This theme was interpreted through the lens of Policy Support (PS) and Perceived Behaviour Control (PBC), highlighting institutional constraints and governance gaps in line with RUDSHAM dimensions.

Table 48: Governance, Policy & Institutional Support

#	Participant	Direct Quotation
A	*Mkushi CF Interview 1*	*"We rarely report cases to the police because they rarely act."*
b	*Mkushi CF Interview 1*	*"Because of thieves, we had to close one of our shops... police could not help much."*
c	*Mkushi CF Interview 1*	*"At one point, we had to use our own resources to catch a gang of thieves terrorising us..."*
d	*Mkushi CF Interview 9*	*"Sending employees to government hospitals is not helpful…"*
e	*Mkushi CF Interview 6*	*"We respect and work with the local chiefs… we had to go and kneel and apologise…"*
f	*Mkushi CF Interview 2*	*"North Swaka Trust (NST) has been helpful in conservation and enjoys much support from CFs and other external funders, but it's not government funded."*
g	*Mkushi CF Interview 1*	*"At some point, the commercial farmers (CFs) wanted to install a community solar farm, but sadly, ZESCO did not cooperate..."*
h	*Mkushi CF Interview 4*	*"It's easy to implement and control sustainability issues within your farm, but quite difficult beyond it - hence, the government needs to come in. Additionally, the wheeling cost should be reduced because currently it's too high."*
i	*Mkushi CF Interview 1*	*"What government should consider doing is giving concessions for charcoal farming and ensuring trees are replanted."*

9.5.4 Technology Access, Theft & Security

The study found that persistent theft and inadequate law enforcement are critical barriers to solar scalability (Table 49). Farmers mitigate risk through private security investments, but these measures reinforce socio-economic disparities. The data underscores the need for decentralised, community-based protection models to support equitable access to solar technologies in vulnerable settings. This was examined using Perceived Ease (PE) and Perceived Behaviour Control (PBC) within RUDSHAM, which helped assess concerns over operational security and end-user autonomy.

Table 49: Technology Access, Theft & Security

#	Participant	Direct Quotation
a	*Mkushi CF Interview 11*	*"Theft is a big problem."*

b	Mkushi CF Interview 2	*"Theft of solar panels is rampant."*
c	Mkushi CF Interview 12	*"Theft is definitely a problem… we had our borehole pump stolen."*
d	Mkushi CF Interview 5	*"Theft does happen. The movement of panels in and out of the house for fear of thieves eventually weakens the system."*
e	Mkushi CF Interview 1	*"Two years ago, our two big solar panels...got stolen... The Zambia Police has not helped much."*
f	Mkushi CF Interview 6	*"Theft is a big problem, and CFs have lost pumps, centre pivot motors, and wires. We have to weld the motors to secure them on the centre pivots."*
g	Mkushi CF Interview 4	*"Theft is a problem in Mkushi, so I ensure that I have watchmen and shepherds with animals at all times, especially because we use solar for strip grazing."*
h	Mkushi CF Interview 9	*"Solar panels are very desirable, so we employ a watchman to guard them…"*
i	Mkushi CF Interview 1	*"Fire and theft are always a problem. We have a watchman for the solar PV, sleeping there every night."*
j	Mkushi CF Interview 1	*"To secure the panels from thieves, we use straps - but sadly, any shade on the panel affects performance."*
k	Mkushi CF Interview 1	*"Vandalism is not a problem here, even though people steal."*
l	Mkushi CF Interview 2	*"The short battery life of normal batteries is a problem unless you use lithium batteries..."*
m	Mkushi CF Interview 2	*"CFs have installed solar power at a government clinic within the farming block."*

9.5.5 Environmental Sustainability & Climate Awareness

The findings in Table 50 revealed that WCFs are increasingly adopting environmental stewardship practices, such as conservation agriculture, reforestation, and sustainable energy alternatives. Their engagement in collaborative conservation bodies reflects a proactive ecological ethic. Nonetheless, external pressures from mining and charcoal commodification threaten long-term sustainability. This section draws from the Green Concern (GC) and Prior Preferences and Practice (PP) components of RUDSHAM to contextualise environmental behaviours and legacy energy practices.

Table 50: Environmental Sustainability & Climate Awareness

#	Participant	Direct Quotation
a	Mkushi CF Interview 1	*"We are very conscious of the environment and have groups to remind and sensitise each other. We pass on this knowledge to our farm employees."*
b	Mkushi CF Interview 1	*"As CFs, we have been spearheading environmentally friendly living... regenerative agriculture... discourages deforestation and charcoal burning."*
c	Mkushi CF Interview 1	*"Urban areas are the biggest drivers of charcoal demand."*
d	Mkushi CF Interview 8	*"Domestic charcoal production is sustainable… but commercialisation is the problem."*
e	Mkushi CF Interview 1	*"Burning down of the bush every year is a big problem... It was a massive fire that took us three days to quench."*
f	Mkushi CF Interview 3	*"Burning is a big problem from villagers who start fires during hunting of small animals and honey collection..."*
g	Mkushi CF Interview 5	*"We teach people not to burn the environment because it's a big problem... burning needs to be controlled."*
h	Mkushi CF Interview 1	*"When flying over Zambia in winter... smoke is everywhere, and visibility is so poor."*
i	Mkushi CF Interview 6	*"Mopani worm, fire, and honey collectors destroy a lot of trees…"*
j	Mkushi CF Interview 2	*"We are very concerned about the manganese mining, which is just next to the main road, and the smelter in the area, which harms the environment, pollutes the Lunsemfwa River, and emits smoke."*

k	*Mkushi CF Interview 2*	*"To protect the environment and the communities around, the CFs came together to buy a farm... They want to conserve it under NST."*
l	*Mkushi CF Interview 3*	*"As CFs, through NST, we are actively ensuring that the conservation of trees and forests around headwaters of rivers and streams is protected..."*
m	*Mkushi CF Interview 4*	*"NST provides alternative income by promoting honey farming, value addition, and the growing of cover crops to replace charcoal burning."*
n	*Mkushi CF Interview 10*	*"NST uses planes to monitor deforestation…"*
o	*Mkushi CF Interview 2*	*"Through Foundations Zambia, CFs are helping the community make charcoal from maize cobs."*
p	*Mkushi CF Interview 1*	*"An alternative to firewood would be maize cobs and cow dung..."*
q	*Mkushi CF Interview 12*	*"To solve deforestation, we need ways to cook sustainably and cost-effectively."*
r	*Mkushi CF Interview 6*	*"We are encouraging conservation farming called Pfumvudza…"*
s	*Mkushi CF Interview 6*	*"I planted 120 hectares of trees… but don't allow them to cut the trees."*

9.5.6 Cultural & Behavioural Factors

Evidence in Table 51 suggests that socio-cultural norms significantly impede the adoption of sustainable technologies. Beliefs linking bush-burning to rainfall and preferences for traditional cooking methods undermine environmentally sensitive innovations. Farmers encounter behavioural resistance rooted in cosmology and custom, underscoring the necessity for culturally informed environmental communication strategies. The Norms (NO) and Prior Preferences and Practice (PP) elements of RUDSHAM were central in identifying entrenched cultural attitudes and behavioural inertia related to energy use.

Table 51: Cultural & Behavioural Factors

#	Participant	Direct Quotation
a	*Mkushi CF Interview 1*	*"Some locals believe that burning the bush contributes to more rain, when the exact opposite is true. It's a dangerous superstition."*
b	*Mkushi CF Interview 2*	*"Energy-saving clay stoves have not been embraced because people prefer firewood and charcoal braziers... for warmth and socialising, fellowship and interaction."*
c	*Mkushi CF Interview 5*	*"Energy-efficient stoves have been introduced but never stay because they can't cook nshima quick enough… laughs..."*
d	*Mkushi CF Interview 7*	*"NST is promoting conservation farming and fuel-efficient stoves… but don't use them."*
e	*Mkushi CF Interview 12*	*"The surrounding community is cutting down our trees for honey and mopani worms."*
f	*Mkushi CF Interview 6*	*"We allow people to fish… but not use mosquito nets… they police themselves."*
g	*Mkushi CF Interview 6*	*"The traditional leaders charge K10… it's a mockery…"*
h	*Mkushi CF Interview 1*	*"Never give things for free - people subconsciously don't appreciate them... Handouts destroy self-worth..."*

9.5.7 Labour Relations & Economic Inclusion

The data in Table 52 shows that White commercial farmers are major contributors to rural employment and welfare. They provide not only jobs but also social infrastructure such as housing, schools, and healthcare. While casualisation and wage debates persist, many farmers demonstrate a commitment to inclusive labour practices and employee advancement, as well as to the country. Community Participation (CoP) and

Economic Cost (EC) from the RUDSHAM framework provided structure for examining how labour dynamics intersect with energy access and rural development. This theme aligns with Norms (NO) and Policy Support (PS) within RUDSHAM, which guided exploration of public discourse, reputational dynamics, and their influence on adoption behaviour.

Table 52: Labour Relations & Economic Inclusion

#	Participant	Direct Quotation
a	*Mkushi CF Interview 1*	*"We, as commercial farmers, create employment for thousands of unskilled workers... Some rise to become supervisors eventually..."*
b	*Mkushi CF Interview 3*	*"The coming of the white Zimbabwean farmers to the Mkushi farming block... caused a huge increase in employment in the area..."*
c	*Mkushi CF Interview 1*	*"Most farmers have a good relationship with their staff... Unhappy workers can take the business down."*
d	*Mkushi CF Interview 6*	*"Casual workers can't be trusted or developed… gratuities are too high."*
e	*Mkushi CF Interview 1*	*"I would like to employ more permanent workers, but it's quite expensive."*
f	*Mkushi CF Interview 4*	*"We have 110 permanent employees, and when doing maize seed, we need another 250 employees for three months... We ensure we take good care of both permanent and temporary staff."*
g	*Mkushi CF Interview 4*	*"I provide housing and grid electricity for [110 permanent employees] for free..."*
h	*Mkushi CF Interview 4*	*"On our farm, we run a clinic and two schools with 100 pupils... We try to motivate our staff because rubbish staff gives rubbish output."*
i	*Mkushi CF Interview 6*	*"I have a school and employ five teachers… we use the government curriculum."*
j	*Mkushi CF Interview 10*	*"I have clinics, schools… and support some government clinics and churches."*
k	*Mkushi CF Interview 2*	*"I know of a colleague who supports his farm employees by growing maize, which he uses to make mealie meal [a maize based staple] ... He also gives farms to his senior employees to do their own farming."*
l	*Mkushi CF Interview 3*	*"I used to loan my employees fertiliser and seed. Fertiliser was repaid when they sold their crop, and for seeds I deducted a little bit from their salaries..."*
m	*Mkushi CF Interview 8*	*"Foundations for Farming Zambia (F4FZ) has helped small scale farmers by creating opportunities for them to supply CFs with cover crops etc… but they still have a charity mentality and at times even fail to manage."*
n	*Mkushi CF Interview 4*	*"I do my very best, so it's quite sad when people condemn CFs and demand that they pay exorbitant salaries. The truth of the matter is that most farmers provide almost everything for their workers."*
o	*Mkushi CF Interview 6*	*"I lost everything when I was expelled from Zimbabwe. It was terrible, but also a blessing in disguise, because Zambia and the Mkushi farmers welcomed us and offered fertile land in the Mkushi farming block - even the head of state, Levy Mwanawasa, came and addressed us. I can confess now that I am 100% Zambian, and I love this country - just like many other commercial farmers who were forced out of Zimbabwe and settled in Zambia."*

9.5.8. Public Perceptions & Media Narratives

The data in Table 53 indicates that study participants perceive a significant gap between their lived contributions to rural development and their portrayal in public and academic spaces. Media and selected scholarly narratives were reported to disproportionately emphasise isolated grievances, while underrepresenting broader socio-economic roles and cumulative local impacts. This pattern suggests the need for more balanced and participatory research approaches that capture the full complexity of rural development actors. Within the RUDSHAM framework, this theme was examined through the lenses of Norms (NO) and Policy Support (PS), which informed the analysis of how public discourse, reputational dynamics, and external narratives shape trust, legitimacy, and technology adoption behaviours in rural contexts.

Table 53: Public Perceptions & Media Narratives

#	Participant	Direct Quotation
a	*Mkushi CF Interview 1*	*"The media has, on many occasions, demonised us—picking disgruntled workers as case studies and taking their word as gospel truth."*
b	*Mkushi CF Interview 1*	*"For the media, a story about how farmers abuse workers would sell better than one where farmers are praised..."*
c	*Mkushi CF Interview 1*	*"It's sad that some researchers... would choose to pick one disgruntled worker's opinion and make conclusions."*
d	*Mkushi CF Interview 9*	*"Previously, there was a large community dependent on stealing maize… but with the coming of many tobacco farmers from Zimbabwe who employed thousands, maize theft has reduced. Such things are rarely reported in the media."*

9.6 Discussion

9.6.1 Community Engagement & Development

The data (refer to Table 46) reveal that White commercial farmers (WCFs) in Mkushi actively engage in a broad spectrum of community development activities that extend far beyond economic extraction. Their involvement includes education (MCF 9.5.2l), health infrastructure (MCF 9.5.2i), spiritual life (MCF 9.5.2n), and targeted charitable interventions such as orphanages and after-school programmes (MCF 9.5.2q). Such initiatives suggest that WCFs are functioning as de facto providers of public goods, particularly in rural areas where state presence remains limited (Matenga and Hichaambwa, 2017; Mondoloka, 2017). This aligns with broader patterns in Sub-Saharan Africa, where private actors often substitute for weak institutional capacity in service provision (Johann et al., 2013).

Community relations appear to be largely positive, with several respondents emphasising mutual respect and reciprocity (MCF 9.5.1a, MCF 9.5.1b). The notion of social embeddedness is particularly evident in practices that promote co-contribution, such as requiring community members to participate in projects to enhance ownership and reduce dependency (MCF 9.5.1g, MCF 9.5.1h). These findings echo Nyoh's (2021) emphasis on participatory, locally anchored development strategies that foster durable community buy-in for sustainability initiatives, including solar PV. This also builds on (Chileshe's (2023) argument that inclusive, non-state governance actors are vital to accelerating rural electrification and co-producing social value.

Such multi-stakeholder collaborations highlight how WCFs may serve not only as service providers but also as institutional innovators in weak governance contexts.

The legitimacy of CFs is also reinforced through institutionalised mechanisms like the Mkushi Farmers Association (MCF 9.5.1e, MCF 9.5.1f), which operates a levy system to redistribute resources. These practices indicate a quasi-formal governance system, consistent with Chileshe's (2023) findings on the importance of inclusive stakeholder frameworks in advancing rural energy transitions.

Moreover, evidence of collaboration with external actors, such as NGOs and foreign volunteers (MCF 9.5.2o, MCF 9.5.2p), illustrates WCFs' role as bridging agents capable of attracting additional development resources. This positions them as influential exogenous actors in rural development, consistent with Le Dong and Mori's (2017) call for recognising external actors in shaping socio-technical transitions. Overall, these practices substantiate WCFs' potential role in Zambia's decentralised energy and development strategies.

9.6.2 Energy Access & Affordability

White commercial farmers in Mkushi demonstrate a proactive, though largely informal, role in rural solar transitions (refer to Table 47). While the rural appetite for solar PV is reportedly increasing (MCF 9.5.2a), affordability remains the principal constraint (MCF 9.5.2b, 9.5.2c), reflecting broader concerns across Zambia about the exclusion of non-elite households from energy access (Chambalile et al., 2024). The expressed willingness by WCFs to host solar plants (MCF 9.5.2h, 9.5.2i) and contribute land or management oversight aligns with Naumann and Rudolph's (2020) call for recognising the role of large-scale agricultural actors in energy transitions. However, commercial viability, particularly the ability to feed power into the national grid (MCF 9.5.2i), remains a critical policy bottleneck, mirroring Stritzke's (2018) emphasis on institutional coordination in Zambia's solar deployment strategies.

More notably, WCFs expressed interest in financing mechanisms that enable rural workers to access solar incrementally (MCF 9.5.2d), and some already provide targeted support to their staff or community members for solar-based livelihoods (MCF 9.5.2e). These micro level interventions align with findings by Tinta et al. (2023), who note that entrepreneurial rural actors are more likely to adopt SHS when affordability and support systems are in place. Similarly, the suggestion to use proceeds from communal farming to fund biogas and solar access (MCF 9.5.2f) signals a bottom-up model of decentralised financing, echoing Zulu's (2016) vision for community-based solar ecosystems.

At the policy level, calls for broader incentives and partnerships (MCF 9.5.2g) highlight the necessity of systemic support. This supports Chambalile et al.'s (2024) recommendation that financial and institutional reforms must complement grassroots efforts to unlock the full potential of renewable energy in rural Zambia. Overall, WCFs are emerging as latent intermediaries in Zambia's decentralised energy future. This supports Dong and Mori's (2017) proposition that actors situated outside the formal energy policy apparatus can initiate valuable bottom-up innovations. It also reflects Mwanza et al.'s (2017) emphasis on the catalytic role of agricultural elites in diffusing solar infrastructure through informal, community-driven arrangements.

9.6.3 Governance, Policy & Institutional Support

White commercial farmers in Mkushi operate within a governance vacuum characterised by limited institutional responsiveness, prompting them to assume quasi-governmental roles in security and service provision (refer to Table 48). As reported, repeated theft and ineffective police response (MCF 9.5.3a, 9.5.3b, 9.5.3c) compel WCFs to self-finance security measures, highlighting the fragility of rural governance infrastructures, an issue well documented in the broader Zambian rural context (Nolte and Subakanya, 2016). Similar frustrations extend to the health sector, where reliance on underperforming public services leads some WCFs to opt to have their own clinics for treating employees (MCF 9.5.3d). These experiences reinforce calls for more robust public-private collaboration to enhance rural service delivery and decentralised infrastructure support (Mondoloka, 2017). Despite some tensions with formal institutions, WCFs maintain constructive relationships with traditional authorities (MCF 9.5.3e), reflecting Nolte's (2016) argument that respectful initial contacts with local power structures are critical for long-term social licence. Additionally, actors like the North Swaka Trust (MCF 9.5.3f) serve as non-state conservation vehicles supported by WCFs, though their impact remains constrained by the absence of government backing, echoing Batisai and Mudimu's (2021) findings on institutional vacuum in rural development partnerships.

The thwarted attempt by WCFs to install a community solar farm due to ZESCO's non-cooperation (MCF 9.5.3g) mirrors structural barriers noted in Zambia's energy sector (Stritzke, 2018), where poor inter-agency coordination hampers decentralised solar initiatives. Policy misalignments, such as high wheeling costs (MCF 9.5.3h), discourage private sector participation in rural solar infrastructure, a critical bottleneck also identified by Chambalile et al. (2024). Farmers' pragmatic calls for regulated charcoal farming and reforestation efforts (MCF 9.5.3i) reflect a growing awareness of sustainable resource management and the desire for incentive compatible policy reforms. As Naumann and Rudolph (2020) argue, recognising exogenous actors like WCFs as informal energy and development intermediaries remains key to unlocking inclusive rural energy transitions. This perspective is reinforced by Chu (2013), who asserts that weak institutional contexts require adaptive governance networks anchored in local legitimacy. Hence, WCF engagement should be strategically institutionalised rather than treated as peripheral to Zambia's energy and policy architecture.

9.6.4 Technology Access, Theft & Security

Widespread theft of solar photovoltaic (PV) components in Mkushi significantly undermines both the viability and scalability of rural energy transitions (refer to Table 49). Respondents describe theft as "rampant" (MCF 9.5.4b) and "a big problem" (MCF 9.5.4a, 9.5.4c, 9.5.4f), reflecting systemic security vulnerabilities that force WCFs to adopt labour and capital intensive protection strategies, such as employing night watchmen (MCF 9.5.4h, 9.5.4j) and welding infrastructure to prevent equipment loss (MCF 9.5.4f). These protective measures increase the operational costs of solar installations and reinforce rural inequalities, given that such security responses are unaffordable for poorer smallholders. The practice of repeatedly moving panels indoors to avoid theft (MCF 9.5.4d) weakens systems, exacerbating the technical fragility of PV units already constrained by short battery life and performance issues (MCF 9.5.4l, 9.5.4j). This reveals the intersection of socio-technical challenges noted by Stritzke and Jain (2021), where infrastructure design must be attuned to the lived realities of theft-prone environments. The failure of formal policing to respond to equipment theft (MCF 9.5.4e) points to broader institutional incapacities and governance gaps, which scholars like Chambalile et al. (2024) and Le Dong & Mori (2017) argue must be addressed through decentralised policy reform and local stakeholder engagement.

Despite these barriers, WCFs remain active agents in promoting solar adoption. Their contribution to powering a local government clinic (MCF 9.5.4m) illustrates their role as informal energy intermediaries, aligning with Naumann and Rudolph's (2020) framing of exogenous actors as key to enabling niche innovations in rural sustainability transitions. However, without systemic policy interventions and improved security infrastructure, the proliferation of solar PV risks entrenching energy exclusion for vulnerable groups and deterring broader participation in Zambia's decentralised energy strategy. Thus, addressing theft is not peripheral, but central to achieving equitable energy access in rural contexts. This resonates with Stritzke and Jain (2021), who note that energy systems in Sub-Saharan Africa must be designed for socio-technical resilience in insecure environments. Without addressing these vulnerabilities, rural solar diffusion risks reproducing, rather than resolving, spatial inequalities in energy access.

9.6.5 Environmental Sustainability & Climate Awareness

The environmental stewardship practiced by WCFs in Mkushi reflects a notable, albeit under-researched, contribution to Zambia's sustainability transitions (refer to Table 50). Farmers demonstrated a collective environmental ethic, often internalised through peer sensitisation groups (MCF 9.5.5a) and embedded in regenerative agricultural practices that discourage deforestation and charcoal dependence (MCF 9.5.5b). Their awareness of the socio-ecological dynamics, such as the urban demand driving charcoal commodification (MCF 9.5.5c) and the adverse impacts of bushfires (MCF 9.5.5e, 9.5.5f, 9.5.5h), aligns with broader critiques of charcoal markets across the Global South (Chambalile et al., 2024; Kabisa et al., 2019; Moombe et al., 2020).

These farmers do not merely diagnose environmental degradation; they act upon it. Responses include implementing controlled conservation farming systems like Pfumvudza (MCF 9.5.5r), tree planting initiatives (MCF 9.5.5s), and education on fire management (MCF 9.5.5g). This is congruent with evidence that successful adoption of sustainable agricultural practices requires both technical adaptation and social mobilisation (Manda et al., 2016; Tanyanyiwa et al., 2022). Of particular significance is their engagement with a farmer-initiated conservation body (the North Swaka Trust), using innovative tools such as aerial surveillance (MCF 9.5.5n) and promoting economic alternatives like honey farming and value-added agroforestry products (MCF 9.5.5m). These strategies are in line with broader arguments that climate-smart solutions must integrate ecological protection with livelihood enhancement (Chikopela et al., 2024).

Furthermore, the WCFs' opposition to harmful extractive industries, such as manganese mining (MCF 9.5.5j), illustrates their emergent role as local environmental monitors, an aspect not commonly associated with agribusiness actors. This also suggests an indirect conflict with the clean energy transition, as manganese is a key component of lithium-ion batteries and renewable energy generation technologies (Park and Melendez, 2024; UNECE, 2024; Valero et al., 2021; World Economic Forum, 2024). Their push for sustainable energy alternatives like making charcoal from maize cobs and cow dung (MCF 9.5.5o, 9.5.5p), is particularly relevant in light of Zambia's energy poverty crisis, offering decentralised, low cost energy options that complement solar PV interventions.

Overall, while the structural inequalities embedded in Zambia's agrarian landscape must not be ignored (Lay et al., 2018; Matenga, 2017), this study suggests that WCFs are playing a hybrid role as both agricultural modernisers and environmental stewards. Their actions offer practical entry points for climate policy and decentralised energy interventions, especially when state support remains fragmented. These findings affirm the argument by Mavesere and Dzawanda (2023) that sustainable agricultural actors can double as environmental stewards and innovation brokers. By integrating conservation with energy innovation, WCFs demonstrate how climate smart agriculture and energy transitions can be pursued in tandem.

9.6.6 Cultural & Behavioural Factors

The socio-cultural dynamics surrounding energy and sustainability transitions in rural Mkushi reveal a complex interface between community norms, technology adoption, and environmental stewardship (refer to Table 51). White commercial farmers emerge as both informants and enforcers of sustainability ethics, yet their efforts often clash with entrenched rural beliefs and practices. For instance, the persistence of bush-burning myths, where locals believe it brings rain (MCF 9.5.6a), reflects a deep-rooted cosmological worldview that undermines environmental conservation efforts. This highlights the necessity of participatory communication strategies for behavioural change, as advocated by Nyoh (2021).

Moreover, the rejection of energy-efficient stoves due to their incompatibility with social rituals (MCF 9.5.6b), inadequate functionality for staple food preparation (MCF 9.5.6c), and lack of adoption despite promotion efforts (MCF 9.5.6d) underscores the cultural embeddedness of energy practices. This aligns with Chambalile et al. (2024) and

Chanda et al. (2025), who emphasise that energy transitions in Zambia are constrained not only by technical and financial barriers but also by social acceptability.

Environmental degradation through deforestation for mopani worms and honey (MCF 9.5.6e), as well as inadequate penalties for environmental harm (MCF 9.5.6g), further reveals governance deficits. In response, some CFs have established informal conservation mechanisms such as community self-policing (MCF 9.5.6f), reflecting emergent forms of localised governance. These practices, though commendable, require institutional reinforcement through stronger policy frameworks and integration into Zambia's decentralised energy strategy.

Additionally, resistance to donor-driven models is evident in WCFs' critique of free distributions, which they argue erode local agency (MCF 9.5.6h). This resonates with Chambalile et al. (2024) and Chanda et al. (2025)) warning that externally imposed interventions, devoid of community buy-in, often fail to yield sustainable outcomes.

Ultimately, the findings suggest that WCFs, while not central actors in formal policy domains, function as important intermediaries, bridging technical solutions and community contexts. Their embedded roles in knowledge dissemination, enforcement, and social influence present an opportunity for more inclusive, culturally attuned energy and environmental interventions in Zambia. Such dynamics reinforce Bhatasara et al.'s (2025) assertion that social norms and cosmologies remain key determinants in the adoption of clean energy. Consequently, WCFs' efforts must be augmented with culturally literate programming that addresses the symbolic as well as material dimensions of energy use.

9.6.7 Labour Relations & Economic Inclusion

White commercial farmers in Mkushi play a discernible and largely positive role in promoting local economic inclusion and community development, particularly through employment creation and social investment (refer to Table 52). In this study, WCFs report employing hundreds of permanent and seasonal workers, offering opportunities for upward mobility, with some workers progressing to supervisory roles (MCF 9.5.7a, 9.5.7b). This aligns with findings by Muzekenyi et al. (2023), who highlight that small-scale commercial farming is pivotal for rural economic development, contributing to job creation, food security, and income diversification.

The provision of social services, such as housing, schools, clinics, and access to grid electricity (MCF 9.5.7f–9.5.7j), demonstrates a strong commitment to local welfare. These practices echo successful models of inclusive agrarian development where commercial farming areas become hubs of rural infrastructure (Matenga and Hichaambwa, 2017). Such investments reflect an informal form of corporate social responsibility that complements weak rural public services, as observed in other sectors across Zambia (Mondoloka, 2017). One WCF's operation of a school with five teachers using the national curriculum (MCF 9.5.7i) supports rural education access, a key enabler of long-term development (Chikopela et al., 2024).

Notably, WCFs also engage in livelihood enhancement for their employees through input credit, land access for farming, and food production schemes (MCF 9.5.7k, 9.5.7l). These efforts align with broader calls for out grower type partnerships and private sector engagement in rural transformation (Johann et al., 2013; Matenga and Hichaambwa, 2017). While concerns around casualisation remain (MCF 9.5.7d), WCFs' expressed desire to offer more permanent employment (MCF 9.5.7e) suggests awareness of this limitation and a willingness to address it where feasible. The integration of ex-Zimbabwean farmers into the Mkushi community further illustrates resilience and productive inclusion. Their contribution to employment and farming revitalization is positively acknowledged (MCF 9.5.7o), supporting earlier findings in Nigeria where displaced Zimbabwean farmers enhanced local agricultural productivity (Adewumi et al., 2013). This reflects the potential of exogenous actors to catalyse rural development, as emphasised by Le Dong and Mori (2017).

In sum, WCFs in Mkushi significantly enhance rural livelihoods and community welfare. Their efforts resonate with broader frameworks advocating for private sector participation in inclusive, sustainable rural development (Naumann and Rudolph, 2020; Taylor, 2024) and offer a constructive model for integrating commercial farming into Zambia's decentralised development agenda. These contributions substantiate Muzekenyi et al.'s (2023) view that commercial agriculture can function as a platform for rural transformation when paired with socially embedded practices. Moreover, the layered nature of WCF employment practices suggests a hybrid model of economic inclusion that deserves further empirical investigation.

9.6.8 Public Perceptions & Media Narratives

The public perception of WCFs in Mkushi emerges as a complex and often contested space, shaped by media narratives and selective representation (refer to Table 53). Several WCFs expressed frustration over negative portrayals in both media and some academic research, arguing that such narratives tend to amplify grievances from isolated individuals while ignoring broader contributions to rural employment and community development (MCF 9.5.8a, 9.5.8b, 9.5.8c). This aligns with insights from Naumann and Rudolph (2020), who note that the role of exogenous actors, such as foreign or white farmers, in sustainability transitions is often oversimplified, leading to skewed assessments that overlook intricate local realities.

The comments from WCFs suggest a perceived disconnect between lived experiences and public discourse, particularly around issues of labour and social integration. For instance, while some studies have critiqued commercial farming for limited socio-economic inclusion (Matenga, 2017), WCFs in Mkushi point to tangible impacts such as reduced theft and increased employment following the influx of Zimbabwean farmers (MCF 9.5.8d). This aligns with Adewumi et al. (2013), who observed that white Zimbabwean farmers settling in Nigeria contributed to local agricultural revitalization and job creation, albeit amid tensions over land and power dynamics.

These tensions highlight the importance of balanced, participatory research approaches recommended by Nyoh (2021), to avoid reinforcing narratives that may hinder collaborative rural energy and development efforts. Recognizing the legitimacy of diverse voices, including that of WCFs, is essential for fostering inclusive, just transitions, particularly in contexts like Zambia where decentralised energy and agricultural systems are still maturing (Stritzke and Jain, 2021). In this regard, reframing WCFs not merely as controversial figures but as underutilised stakeholders in rural sustainability efforts aligns with calls for more integrative and evidence based development models. This also echoes Mondoloka's (2017) call for more reflexive, participatory methodologies that foreground the lived realities of corporate actors in rural development. Better narrative balance could help depoliticise WCFs' contributions and encourage collaboration between public, private, and community actors in advancing equitable energy transitions.

9.7 Policy Recommendations

Drawing from the empirical evidence presented in Mkushi, this study offers six actionable policy recommendations tailored to Zambia's national development priorities. These recommendations aim to support solar PV adoption, promote community inclusion, and enhance environmental sustainability through strengthened institutional frameworks and stakeholder collaboration.

9.7.1 Formalise Commercial Farmer Role in Electrification

The Ministry of Energy, in collaboration with the Rural Electrification Authority (REA), should formally integrate White commercial farmers (WCFs) into Zambia's off-grid energy policy framework. Given WCFs' capacity to offer land, management oversight, and capital for solar projects, the government should develop a structured public-private partnership model that supports shared solar mini-grids and facilitates grid interconnection through revised licensing and feed-in tariff protocols. This will bolster decentralised electrification in underserved rural regions.

9.7.2 Launch National Solar Security Initiative

Solar equipment theft significantly threatens solar scalability in rural Zambia. The Ministry of Home Affairs and Internal Security, working in conjunction with local government authorities and farmer associations, should establish a national rural solar security initiative. This should include dedicated rural security patrols and the introduction of affordable solar theft deterrents. The Ministry of Technology and Science should collaborate with non-governmental organizations such as the Netherlands Development Organisation (SNV Zambia) and Practical Action Zambia to pilot and scale up cost-effective PV security technologies.

9.7.3 Incentivise Green Farming and Conservation

The Ministry of Green Economy and Environment and the Ministry of Agriculture should introduce a joint incentive programme that formalises and supports conservation practices already implemented by WCFs. This programme should provide fiscal incentives and extension support for initiatives such as afforestation, Pfumvudza (conservation agriculture), sustainable charcoal alternatives, and watershed protection. Oversight should be provided by the Zambia Environmental Management Agency (ZEMA), ensuring synergy with climate resilience strategies.

9.7.4 Community Solar Financing Through Cooperatives

To enhance access to solar PV systems among rural populations, the Ministry of Small and Medium Enterprise Development and the Zambia Development Agency should develop cooperative-based financing schemes modelled on informal systems already supported by WCFs. These should include input credit, solar leasing, and revolving loan funds targeting women, youth, and smallholder farmers. Implementation should involve civil society organizations such as the Zambia Social Investment Fund (ZAMSIF) and local community-based organizations.

9.7.5 Promote Inclusive Media and Research

The Ministry of Information and Media, in partnership with academic institutions and think tanks such as the Zambia Institute for Policy Analysis and Research (ZIPAR), should spearhead a national campaign for inclusive rural development storytelling. This should encourage evidence-based reporting that accurately reflects the roles of all actors, including WCFs, in sustainability transitions. A research ethics framework should also be developed to guide participatory methodologies and discourage reductionist portrayals of rural dynamics.

9.7.6 Institutionalise Multi-Stakeholder Planning Platforms

The Ministry of Local Government and Rural Development should establish district-level multi-stakeholder forums that bring together WCFs, smallholder representatives, traditional leaders, civil society, and development partners. These platforms should support co-creation of community infrastructure, renewable energy projects, and social investments. International development partners such as the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and the United Nations Development Programme (UNDP) should be engaged for technical and financial support.

By implementing these recommendations, Zambia can strategically harness the potential of White commercial farmers as key collaborators in decentralised energy, environmental conservation, and rural development, fostering inclusive and sustainable transformation.

9.8 Conclusion

This study set out to examine whether, and how, White commercial farmers (WCFs) in Mkushi, Zambia contribute to solar photovoltaic adoption, community development, and environmental sustainability in rural contexts. Anchored in the Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM), the research offers important empirical and theoretical insights into a triadic nexus that has hitherto been largely overlooked: the intersection of decentralised solar energy transitions, rural development imperatives, and the often-contested role of WCFs.

9.8.1 Key Findings

Three overarching findings emerge. First, WCFs are actively contributing to community development by providing essential services such as education, health, and employment in contexts where the state's presence is weak. Second, although their involvement in solar energy adoption is primarily informal, WCFs show a strong willingness to facilitate solar transitions by offering land, infrastructure, and financing mechanisms that benefit workers and local communities. Third, their environmental stewardship is evident in climate-smart agriculture, reforestation, and conservation partnerships, indicating their dual role as agricultural modernisers and sustainability actors.

The study also revealed critical systemic barriers, including policy misalignments, institutional fragmentation, and persistent insecurity, particularly theft of solar equipment, which undermine the scalability of rural energy solutions. Nevertheless, WCFs demonstrate agency, adaptability, and embeddedness within local social systems, allowing them to function as informal intermediaries for decentralised development.

9.8.2 Contribution to Knowledge

This research makes several original contributions. Most notably, it is the first scholarly investigation to explore the integrated dynamics of solar adoption, sustainability, and rural development through the lens of white commercial agriculture. Secondly, the application of the RUDSHAM framework presents an innovative analytical tool for understanding and addressing complex social problems at the intersection of stakeholder behaviour, governance gaps, and technological transitions. The study thus extends the conceptual boundaries of energy justice, community development, and environmental policy by recognising exogenous actors as underutilised agents in rural transformation.

9.8.3 Future Research Recommendations

Future research should expand the geographical and temporal scope by conducting longitudinal studies across multiple farming regions in Zambia. A nationwide study guided by RUDSHAM would help test the generalisability of findings and refine the framework's applicability in diverse rural environments. Furthermore, comparative studies across Sub-Saharan Africa would illuminate regional variances in the roles of foreign and commercial agricultural actors in sustainability transitions.

9.8.4 Study Limitations

The primary limitation of this study lies in its relatively short duration, which restricted the ability to capture seasonal fluctuations and longer-term policy developments.

Additionally, while the research was conducted within a specific region in Zambia, this allowed for an in-depth, context-specific understanding that may differ in other locations. Furthermore, data collection focused exclusively on the perspectives of commercial farmers, as the study specifically aimed to explore the role of White commercial farmers as potential entry points for community level solar adoption and financing. Future research would benefit from incorporating the perspectives of a broader range of stakeholders to provide a more holistic understanding of the dynamics at play. Nonetheless, these limitations do not detract from the robustness or credibility of the findings, which are grounded in rich empirical evidence and informed by triangulated insights.

Chapter 10: Nexus between solar-PV adoption and wild food sustainability: Case of income from honey, fruits, traditional-beer, and vegetables in rural Zambia. (Article 6)

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Summary: This article examines the intersection between edible non-timber forest products (ENTFPs) and the adoption of solar photovoltaic (PV) systems in rural Zambia, with a focus on how income derived from wild foods, such as honey, traditional beer, wild fruits, and indigenous vegetables, supports solar energy access. In the context of severe energy poverty, unreliable hydroelectric supply, and increasing ecological vulnerability, rural households are turning to ENTFPs both as nutritional staples and as income-generating resources.

Abstract: The study finds that revenues from ENTFPs often exceed those from subsistence agriculture and are pivotal in enabling households to self-finance solar PV systems. However, the commercialisation of these products, particularly wild honey and traditional beer, carries significant environmental risks including overharvesting, loss of biodiversity, and forest degradation. Social impacts were also observed, such as intra-community conflicts over resource access and gender disparities in ENTFP-based earnings. While solar PV adoption reduces reliance on charcoal and aligns with Zambia's environmental goals, it simultaneously intensifies pressure on natural resources due to the growing financial dependence on ENTFPs.

Recommendations: Recommendations include the development of robust policy frameworks to promote sustainable harvesting and equitable value chains for ENTFPs. Integrating solar PV into rural development should be accompanied by community-driven conservation strategies and educational initiatives aimed at balancing ecological protection with rural livelihoods.

Overall contribution: This article addresses Thesis Objectives 1 and 5 by critically analysing the environmental trade-offs and livelihood implications of solar PV expansion. It adds granularity to the thesis by empirically connecting decentralised energy access to wild food economies and the complex socio-ecological systems in which they are embedded.

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Keywords: Solar Photovoltaic (PV) Adoption; Edible Non-Timber Forest Products (ENTFPs); Sustainable Livelihoods; Energy Access; Rural Development; Environmental Sustainability

10.1 Introduction

Zambia faces a significant energy access challenge, with rural electrification rates below 15%, leaving over 12 million people without electricity (Kapole et al., 2023; MOE, 2024; Timmermann and Smith-Hall, 2019). The country heavily relies on hydroelectric power from the Zambia Electricity Supply Corporation (ZESCO) Limited, which accounts for over 85% of its energy mix, making it highly vulnerable to climate-induced droughts (ERB, 2024; MOE, 2024). Recent droughts have led to severe power shortages, causing extended load-shedding of up to 21 hours per day in grid connected areas (ZESCO, 2024a). In response, ZESCO has restricted residential electricity to three hours per day on a rotating basis (NDN, 2024), emphasizing the urgent need for alternative energy solutions.

As of 2024, Zambia's installed generation capacity reached 3,871.32 MW, up from 3,811.32 MW in 2023, with solar power contributing to this growth (ERB, 2024). However, the country still faces a power deficit of approximately 1,360 MW, with available generation at only 1,040 MW. Even with 410 MW of imported electricity, Zambia experiences a shortfall of 950 MW, resulting in persistent load shedding (MOE, 2024; ZESCO, 2024a). To address energy insecurity, the government has implemented initiatives such as tax exemptions on solar equipment, the Rural Electrification Authority (REA), and the Off-Grid Taskforce to expand rural electrification (ERB, 2024).

Renewable technologies, particularly solar photovoltaic (PV) systems, offer a viable solution to mitigate energy shortages and improve livelihoods in rural Zambia (Pitshou et al., 2023; Yekini et al., 2024). Solar PV enhances rural economies by providing reliable electricity, boosting agricultural productivity, and fostering local enterprises (Ngonda et al., 2023). Access to electricity enables essential activities such as lighting, mobile phone charging, and small appliance use, contributing to household development (Chidembo et al., 2022). However, high initial costs and expensive mini-grid tariffs limit widespread adoption, particularly among low-income households (Bhattacharyya and Palit, 2021; Mulenga et al., 2023; Stritzke and Jain, 2021).

In rural Zambia, where grid electricity remains scarce, solar PV adoption is increasingly financed through agriculture and wild food harvesting—including honey, fruits, traditional beer, and vegetables. These income streams serve as economic enablers of decentralised energy solutions, supporting sustainable livelihoods and enhancing energy access.

10.1.1 Background

In Zambia's rural regions, the integration of solar PV systems with income from non-timber forest products (NTFPs) offers a promising approach to enhancing energy access. All (100%) rural households in Zambia gather fruits, 86% harvest leafy vegetables, 86% gather mushrooms, 82% collect insects, 75% harvest bushmeat, 73% collect tubers, and 14% catch fish (Steel et al., 2022). However, the informal nature of the non-timber forest products (NTFP) trade limits its economic potential and encourages unsustainable harvesting practices, threatening biodiversity (Anyango et al., 2018; Zulu et al., 2019). NTFPs, including wild honey, wild fruits, traditional beer, and wild leafy vegetables, constitute essential livelihoods for approximately 60% of rural households (Derebe and Alemu, 2023; Kalinda and Bwalya, 2014). Wild fruits and leafy vegetables provide critical nutrition and income, while traditional beer and wild honey offer significant market potential. The estimated collection of wild foods alone exceeds 380 million litres annually, showcasing the extensive utilization of forest resources (Mulenga et al., 2012; Steel et al., 2022). NTFP based revenues can contribute up to 32-35% of rural household incomes, offering financial means for self-financing solar PV investments (Mulenga et al., 2011). Seasonal NTFP revenues can help bridge economic gaps, facilitating access to renewable energy (Shackleton et al., 2024; Timko et al., 2010).

Access to formal credit remains limited for many rural households, making NTFP monetization a crucial source of funds for solar PV adoption (Amadu and Miller, 2024). Leveraging local resources aligns with sustainable development goals by fostering economic resilience and minimizing environmental degradation (Amadu and Miller, 2024). However, unsustainable harvesting poses risks of resource depletion and ecological harm (Anyango et al., 2018; Mulenga et al., 2011). A balanced strategy integrating sustainable NTFP management with renewable energy deployment is vital for maintaining ecological and economic health (Derebe et al., 2023).

10.1.2 Study Justification and Significance

The convergence of self-financed solar PV adoption and income generation from ENTFPs represents a pivotal opportunity to combat rural energy poverty and drive sustainable development in Zambia. Central and Lusaka Provinces illustrate this synergy, where ENTFPs like wild honey, wild fruits, traditional beer, and leafy vegetables are critical for rural livelihoods, particularly during agricultural downturns (Mclain and Lawry, 2015; Mulenga et al., 2012). Sustainable NTFP harvesting is essential to preserve biodiversity, curb deforestation, and enhance community resilience (Mulenga et al., 2011; Shackleton and Shackleton, 2014).

Integrating solar PV systems within rural economic structures provides dual benefits, reducing dependence on biomass and kerosene while lowering CO_2 emissions and mitigating deforestation (Wassie and Adaramola, 2021). NTFP-derived income streams can support self-financing models, empowering rural households to transition to renewable energy (Shackleton and Shackleton, 2014). This research explores how combining solar PV adoption with sustainable NTFP management can improve energy access, bolster rural economies, and promote environmental conservation, fostering resilience and long-term sustainability.

10.1.3 Research Problem

The adoption of solar photovoltaic (PV) systems among rural households in Zambia remains poorly understood, despite their potential to mitigate energy poverty. Moreover, the environmental and social implications of income-generating activities linked to edible non-timber forest products (ENTFPs) in these communities require further exploration. This highlights the need for a critical assessment of the interplay between NTFP-derived income, solar PV adoption, and their associated benefits and limitations.

10.1.4 Research Objectives

This study aims to examine the relationship between income from edible ENTFPs and the adoption of solar PV systems among rural Zambian households. Specifically, it will assess financing mechanisms tied to ENTFPs, evaluate their effectiveness, and explore the environmental and societal impacts of ENTFP-related income-generating activities within these communities.

10.1.5 Research Questions

What financing mechanisms linked to ENTFPs facilitate solar PV adoption in rural Zambia? What are their benefits and limitations? How do ENTFP-based activities affect the environment and society?

10.2 Literature Review

This literature review examines the socio-environmental effects of income-generating activities linked to edible Non-Timber Forest Products (ENTFPs) in rural Zambia, with emphasis on self-financed solar photovoltaic (PV) systems. The review provides insights into how ENTFPs, including wild honey, traditional beer, wild fruits, leafy vegetables, nuts, and tubers, intersect with solar energy adoption, influencing local livelihoods and ecological sustainability.

10.2.1 Wild Honey

Wild honey and beekeeping are essential livelihood sources in rural sub-Saharan Africa, including Zambia, where organic honey and beeswax production offer significant economic benefits, notably in Mwinilunga (Lowore, 2020). Approximately 4% of Zambian households engage in honey production alongside other NTFPs like fuelwood and medicinal plants (Kalinda and Bwalya, 2014). Beekeeping diversifies income and enhances resilience against environmental challenges such as droughts, increasing household revenue by up to 11% (Abro et al., 2022). However, wild honey harvesting presents ecological risks. Unsustainable practices, such as using fire to extract honey, contribute to deforestation and biodiversity loss (Ricketts and Shackleton, 2020). Moreover, overexploitation of wild bees threatens pollination systems crucial for ecosystem health (Addi & Bareke, 2014; Mickels-Kokwe, 2006).

Addressing these risks requires sustainable management to preserve both ecological integrity and economic viability (Mulenga et al., 2011; Vanbergen et al., 2014).

10.2.2 Traditional Beer

Traditional beer production remains an important livelihood in rural Zambia, contributing to income and cultural practices, especially in regions with high consumption rates (Paltzer et al., 2021). Dominated historically by women, beer brewing offers economic empowerment but also presents complex socioeconomic and environmental challenges (Rogerson, 2019). Increased commercialization has led to social issues, including alcohol dependency and related health problems such as HIV/AIDS and domestic violence (Naamara and Muhwezi, 2014; Rich et al., 2015). The use of agricultural grains for brewing may exacerbate food insecurity, as it diverts resources from essential food production (Paltzer et al., 2021). Environmental degradation from traditional brewing, including deforestation and water pollution, also poses significant concerns (Gumbo et al., 2013). In Zambia, sustainable practices must balance economic gains from beer production with community health and environmental conservation (Norrgren et al., 2000).

10.2.3 Wild Nuts

Wild nuts and other NTFPs are critical for rural livelihoods in Zambia, providing income and nutrition, particularly for women and children (Kalinda and Bwalya, 2014; Steel et al., 2022). However, commercialization poses sustainability risks, such as deforestation and overharvesting (Murye and Pelser, 2018). Initiatives like Wild Fruits of Africa seek to enhance rural livelihoods, but unsustainable practices threaten ecosystem health and exacerbate poverty (Christian and Kasumi, 2015). Seasonal income from wild nuts, while beneficial, underscores the need for sustainable harvesting to preserve long-term economic and ecological viability (Zulu et al., 2019).

10.2.4 Wild Leafy Vegetables

Wild leafy vegetables contribute significantly to the nutrition and incomes of rural Zambian households, particularly among women (Cyril et al., 2024; Qwabe and Pittawaty, 2023). These nutrient-rich foods enhance food security in resource-poor areas (Mercy et al., 2017). In Zambia, wild leafy vegetables form a substantial part of local economies, with millions of litres of wild foods harvested annually (Arumugam et al., 2020; Steel et al., 2022). Despite their importance, commercialization brings environmental challenges, such as habitat loss and unsustainable harvesting (Murye and Pelser, 2018). The lack of formal cultivation practices exacerbates resource depletion, highlighting the need for integrated approaches that balance economic benefits and environmental sustainability (Arumugam et al., 2020).

10.2.5 Wild Fruits

Wild fruits, including species like Uapaca kirkiana and Parinari curatellifolia, are integral to the food security and livelihoods of rural Zambian households (Kalaba et al., 2009). Their high nutritional value makes them vital during food-scarce periods (Akinnifesi et al., 2004; Bvenura and Sivakumar, 2017). Beyond consumption, commercialization of wild fruits is a critical income source, with about 80% of rural households depending on these products (Ickowitz et al., 2021). However, sustainability challenges arise from overharvesting, which threatens biodiversity and ecosystem stability (Hudson et al., 2020). Declining populations of key species such as Dioscorea hirtiflora highlight the need for effective regulatory frameworks to promote sustainable use and mitigate environmental degradation (Anyango et al., 2018).

10.2.6 Wild Tubers

Wild tubers, including Dioscorea hirtiflora, play a crucial role in the livelihoods of rural Zambians, contributing to food security and income generation (Zulu et al., 2019). Their collection forms a significant part of rural income strategies across Africa (Derebe et al., 2023). However, overharvesting poses risks to biodiversity and threatens the sustainability of wild tuber resources (Murye and Pelser, 2018). In Zambia, declining populations of key species highlight the need for sustainable management to ensure the viability of this critical income source (Zulu et al., 2019).

10.2.7 Solar PV-Based Agri-Processing and Value Addition in Rural Zambia

The integration of solar photovoltaic (PV) technology in agri-processing presents a significant opportunity for enhancing rural livelihoods in Zambia. While the high initial costs and limited power output of solar PV remain challenges (Otiti and Soboyejo, 2006; Tong et al., 2015), innovative applications, such as solar-powered irrigation pumps and crop dryers, have demonstrated potential for increasing agricultural productivity and value addition (Tariq et al., 2021). Solar cabinet dryers with forced circulation have been employed to dehydrate local produce, creating employment and reducing post-harvest losses (Tyagi et al., 2024). In Zambia, mechanised cassava processing has been linked to poverty reduction, highlighting the transformative impact of energy access on rural economies (Abass et al., 2017). However, scaling such interventions requires targeted government support and financing mechanisms to ensure affordability and adoption (Middelberg, 2017).

10.2.8 Productive Use of Solar PV

Beyond agri-processing, solar PV technology plays a crucial role in rural electrification and economic development. In Zambia, micro-hybrid biomass-solar PV power plants have been proposed as a sustainable solution, providing electricity for lighting, refrigeration, and small businesses (Makai and Chowdhury, 2017; Makai and Popoola, 2024). The integration of solar PV in farm operations has been shown to enhance productivity, reduce reliance on wood fuel, and improve living standards (Chambalile et al., 2024). However, widespread adoption is hindered by high costs, inadequate infrastructure, and limited technical capacity, necessitating targeted policies and financial incentives (Ajayi et al., 2024; Durga et al., 2024).

10.3 Theoretical Framework to Inform the Study

The current study sets out and utilises the new Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM) to help explain the degree to which self-financed solar PV systems in rural areas of Africa impacts and affects rural society and the environmental. The RUDSHAM framework (see Fig. 39) integrates three main theoretical models to understand the factors influencing the adoption of renewable energy technologies in rural areas. It combines the Technology Acceptance Model (TAM), Diffusion of Innovations Theory (DOI), and Theory of Planned Behaviour (TPB) to focus on internal factors affecting adoption willingness. TAM highlights performance expectancy, effort expectancy, social influence, and facilitating conditions as key drivers of technology adoption (Ajzen, 1991; Davis, 1989; Rogers, 2003a; Venkatesh and Davis, 2000). Diffusion of Innovations Theory explains the stages and factors influencing the spread of new technologies over time (Rogers, 2003a). TPB suggests that behavioural intentions are shaped by attitudes, subjective norms, and perceived behavioural control (Ajzen, 1991). Additionally, RUDSHAM incorporates Social Learning Theory, which emphasises the role of observation and imitation in shaping attitudes and adoption decisions (Bandura, 1977). Social dynamics, such as peer effects and active communication within social networks, significantly influence individuals' decisions to adopt renewable energy technologies.

By combining internal factors from TAM, DOI, and TPB with external influences from Social Learning Theory and peer effects, RUDSHAM offers a comprehensive understanding of the multifaceted factors driving renewable energy adoption in rural developing areas. This holistic approach recognises the complex interplay between individual beliefs, social influences, and community dynamics in shaping adoption behaviours. The framework provides valuable insights for policymakers, researchers, and practitioners aiming to promote sustainable energy transitions. RUDSHAM's alignment with a mixed-methods research approach, including in-depth interviews, focus groups and observations, ensures a thorough examination of solar PV adoption in rural Zambia. This integration of theoretical and methodological rigour offers a robust foundation for investigating the complex factors impacting solar PV adoption, facilitating the development of effective strategies for sustainable energy development.

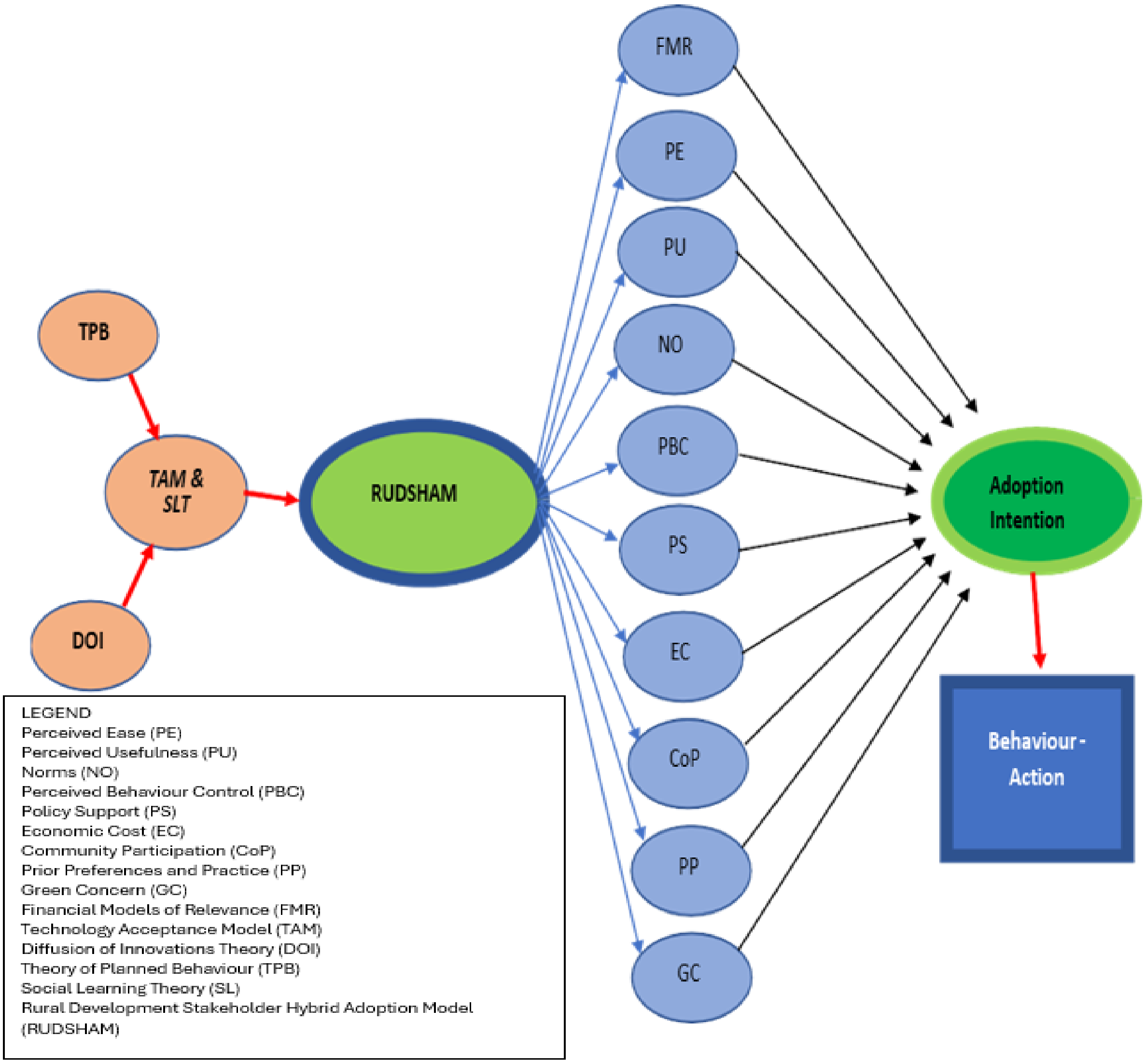

Figure 39: RUDSHAM Hybrid Adoption Model

The Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM) is suitable for analysing the environmental and social impacts of self-financed solar PV systems in rural Zambian rural households. By integrating perceived ease, usefulness, social norms, and behaviour control, RUDSHAM captures key factors influencing adoption. Policy support, economic cost, and community participation contextualise the socio-economic environment, while green concern and financial models highlight sustainability and financing challenges. The framework's comprehensive approach aligns with assessing energy access, sustainability, and rural livelihoods, offering a valuable theoretical lens to understand household decision-making in the context of solar PV systems adoption. For details on the description of how each attribute of the RUDSHAM framework assisted, refer to Appendix B.

10.4 Research Methodology

10.4.1 Research Strategy and Data Collection Methods.

The research was conducted over 6 months (October 2022 to March 2023) across 3 remote rural areas in Zambia: Mkushi Rural (Central Province), Kapiri Rural (Central Province), and Chongwe Rural (Lusaka Province) (see Fig. 40). These locations were strategically chosen for their relative isolation and lack of access to the national power grid. A 4-week pre-testing pilot study was conducted with 5 participants in Luano village (Chingola Rural, Copperbelt Province) to ensure the validity and reliability of the research instruments. One research assistant, fluent in English and several local languages (Bemba, Tonga, Soli, Lamba, and Nyanja), facilitated data collection. The primary investigator is also fluent in English and has a working knowledge of Bemba, Nyanja and Lamba.

The data collection involved in-depth interviews, ranging in duration from 30 minutes to 60 minutes, with 40 rural farmers, 16 commercial farmers, and 3 key stakeholders from solar energy companies and government policymakers. Additionally, 7 focus group discussions (FGDs), each comprising 8 participants from the selected rural areas (3 from Kapiri, 2 from Mkushi and 2 from Chongwe), were conducted to capture a range of opinions and views from the communities. To address gender sensitivity and dominance issues in FGDs, sessions were facilitated by village headmen or councillors, taking advantage of their trusted positions within the community. Mixed and separate discussions ensured diverse perspectives from both men and women, with participants receiving refreshments and tokens of appreciation.

Recorded interviews and photographs, taken with consent, were securely stored on the University's OneDrive cloud account with restricted access to ensure data security. Data analysis involved coding interview transcripts, using colour codes and NVIVO 14, into specific themes and extracting relevant direct quotations to supplement structured interview data. A pilot study interview was conducted resulting in minor adjustments to the protocol based on the pilot results. This multifaceted qualitative approach, including in-depth interviews, FGDs, photovoice, and observations, ensured the validity and reliability of findings by representing various stakeholder viewpoints.

Ethical approval from the University of Reading Ethics Committee (UK) was obtained in 2022, and informed consent protocols were strictly adhered to, ensuring the study's compliance with ethical standards. By integrating the RUDSHAM framework with rigourous research methods, this study provides valuable insights for policymakers, researchers, and practitioners focused on promoting sustainable energy transitions in Zambia and other developing countries.

Figure 40: Map of Zambia. Map sources: UN 2022. Map of the world.

10.5 Research Findings

10.5.1 Rural Income via RUDSHAM Evidence

The Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM), through interviews and focus group discussions (FGDs), has identified a range of income-generating activities prevalent in rural Zambia. These activities form the backbone of subsistence and local economies but also have varied environmental and social implications. RUDSHAM framework plays a crucial role in supporting the findings of this study by providing a multidimensional analytical lens to assess solar PV adoption's impact on rural livelihoods in Zambia. The study reveals that income generated from wild honey, traditional beer, wild fruits, and vegetables contributes significantly to household sustainability, often influencing solar PV affordability. For example, Perceived Usefulness (PU) aligns with findings that solar PV enhances livelihoods by enabling investments in productive activities such as honey sales (a2.3) and beer brewing (b2.3). Economic Cost (EC) contextualises how limited financial resources impact solar PV adoption, as rural households rely on seasonal income from wild foods to pay for solar PV lighting systems (c2.1, d2.5). Norms (NO) highlight the interplay between cultural acceptance and economic behaviour, such as the ethical dilemmas in honey collection (a3.3) and the unregulated beer industry (b3.4). Additionally, Green

Concern (GC) addresses environmental sustainability challenges, such as deforestation linked to honey harvesting (a2.5, a3.2) and the overexploitation of munkoyo roots (d3.3). Financial Models of Relevance (FMR) further illuminate the need for innovative financing solutions, given that income from wild food trade helps cover solar loan repayments (c2.2, d2.7). Thus, RUDSHAM provides a structured framework for understanding the complex socioeconomic and environmental factors shaping solar PV adoption in rural Zambia.

10.5.2 Demographic Profile

The study captured a diverse demographic composition of respondents. In terms of age distribution, 35% were between 19 and 35 years, followed by 34% aged 46 to 55 years, 19% aged 36 to 45 years, 9% aged 56 years and above, and 3% below 18 years. Gender representation was evenly split, with 50% male and 50% female. Monthly income levels varied, with 35% earning between K5,001 and K10,000, 29% earning K10,001 to K20,000, 28% earning below K5,000, and only 8% earning above K20,000. The majority (78%) were married, while 18% were single and 4% widowed. Education levels were generally low: 64% had a junior certificate or below, 33% reported no formal education, and only 3% held a high school certificate. These demographic insights provide a crucial foundation for understanding the socioeconomic context influencing solar PV adoption in rural Zambia. Solar energy items owned by respondents included primarily solar torches (90%), solar chargers (80%), Solar Home Systems (70%), and a few solar water pumps (5%).

(a) Wild Honey

The direct quotations illustrate the economic and cultural importance of wild honey, highlighting both its benefits and challenges. Honey is highly valued for its culinary and medicinal uses, providing a reliable income for many rural households (a2.2, a2.3, a3.1). However, its collection often involves harmful practices such as cutting or burning trees, contributing to deforestation and occasional forest fires (a1.1, a2.5, a3.2). Despite its profitability, honey collection is risky due to bee stings, smoke inhalation, and encounters with wildlife (a2.4, a3.1). High demand has also led to practices like artificial hives and adulteration, reflecting both ingenuity and ethical concerns (a3.3).

(a1) Illustrative Direct Quotations from Commercial Farmers' Interviews

(a1.1) "…That's why people indiscriminately cut trees, even for simple things like honey or ifishimu (Mopani worms) ..." (CF Interview 16)

(a1.2) "Look at this big tree that has just been cut down...There was something in that tree he wanted, either the Mopani worms or the honey …" (CF Interview 10)

(a1.3) "If I take you through this forest, you'll see some beautiful trees that have been cut down…" (CF Interview 11)

(a2) Illustrative Direct Quotations from Rural Farmers' Interviews

(a2.1) "I collect 'Ubuchi' (Honey) from different places like trees, anthills, or underground burrows…I use smoke to collect the honey from beehives. The problem these days is that there are very few trees." (Chongwe interview 12)

(a2.2) "The good thing about honey is that it is easy to store, doesn't go bad, and people love honey - they are willing to buy it as a food sweetener or for medicinal use…" (Luano interview 4)

(a2.3) "…a 2.5ltr sells for $15 (K300), and natural honey is always on high demand…it sustained me and helped me buy a good bicycle, household items and even pay back the solar lighting loan…" (Mkushi interview 3)

(a2.4) "Honey is not easy to collect… apart from bee stings, there is also smoke inhalation and possible encounter with the snakes..." (Kapiri interview 18)

(a2.5) "When the beehive is in a tree… , I start a fire around or in the tree…If the beehive is in a difficult position…, I may cut off the branch or…the tree…" (Kapiri interview 13)

(a2.6) "When I find a beehive, …I collect the honey as quickly as possible because if I leave it, someone else might come and take the honey..." (Mkushi interview 8)

(a3) Illustrative Direct Quotations from Rural Farmers' FGDs

(a3.1) "We can boast of eating pure natural honey… Some people make lots of money from honey, evidenced by their smart phones, iron sheet roofs and bigger solar lighting system loans, but…people sometimes get badly stung and risk their lives." (Mkushi FGD 2)

(a3.2) "Sometimes the honey collectors… cut down trees to access the honey. We have seen big trees that end up completely burnt or destroyed in the process… In other cases, they accidentally start forest fires…" (Kapiri FGD 1)

(a3.3) "Due to high demand for honey from all over, some households are making artificial beehives. Sadly, other honey traders resort to add other sweet fluids to increase the volume of honey…" (Chongwe FGD 2)

(b) Traditional Beer

The direct quotations highlight the dual role of traditional beer in rural communities as both a source of income and a social challenge. While beer brewing, often led by women, supports livelihoods by funding education and household needs (b2.3, b3.4), its unregulated production poses health risks, including illness from unsafe additives (b3.1, b3.2). Excessive consumption drives social issues like violence, criminality, and family breakdowns (b1.1, b2.1, b3.3). The affordability and widespread availability of traditional beer make it culturally significant but also contribute to its overuse and associated health and societal risks (b3.1, b3.4).

(b1) Illustrative Direct Quotations from Commercial Farmers' Interviews

(b1.1) "Beer drinking is a problem in this area, especially for men who don't have jobs... they end up engaging in illegal activities like stealing to raise alcohol money." (CF Interview 16)

(b1.2) "I am always careful when driving because if you're not, you might hit a drunk person… Even some women…putting themselves in danger of being sexually harassed..." (CF Interview 11)

(b2) Illustrative Direct Quotations from Rural Farmers' Interviews

(b2.1) "My husband and I divorced because all he did was drink, womanise, and beat me, especially when he was drunk…" (Kapiri Interview 3)

(b2.2) "…some of the men, when drunk, engage in unruly behaviour, insult others, become violent, and engage in criminal activities…" (Mkushi interview 4)

(b2.3) "Traditional beer (mostly brewed by women), and it has helped many of them to educate their children, have a decent life …., pay for solar lighting for the homes…" (Chongwe Interview 2)

(b3) Illustrative Direct Quotations from Rural Farmers' FGDs

(b3.1) "Traditional beer is good because it's affordable and helps people relax… However,..because it's unregulated, some brewers end up making fatal brewing mistakes." (Mkushi FGD 2)

(b3.2) "You consume traditional beer at your own risk,… many who take it have red/pinkish lips, stomach problems, and poor health… Sometimes, to meet demand, brewers add illegal chemical catalysts…" (Kapiri FGD 1)

(b3.3) "Many men in this village are drunkards, and some, out of carelessness and sleeping with prostitutes, have contracted deadly diseases like HIV and STIs…, many children have been orphaned…" (Chongwe FGD 1)

(b3.4) "We are aware…the production/sale of kachasu are illegal due to its risks and the unregulated… production. However, it remains popular… due to its affordability and availability" (Chongwe FGD 3).

(c) Wild Fruits

Wild fruits play a critical role in rural livelihoods, serving as a source of nutrition, energy, and income. They are consumed, preserved, and sold to urban markets, often aiding households in covering essential expenses like solar lighting loans (c2.1, c3.2, c3.5). However, unsustainable practices, including cutting trees for access or charcoal production, threaten species like Masuku, highlighting the need for conservation (c2.3, c3.6). The cultural significance of these fruits is evident in their diverse uses, such as syrup production from Impundu (c3.3), while equitable access by locals is supported by some commercial farmers (c1.1, c1.2).

(c1) Illustrative Direct Quotations from Commercial Farmers' Interviews

(c1.1) "I allow workers and some villagers to collect wild fruits from my farm,… in a sustainable manner… I understand the importance of living in harmony with the 'owners' of the land." (CF Interview 6)

(c1.2) "Since we don't consume all the wild fruits, it's only fair that we allow the locals to collect the fruits which they can eat and sell…" (CF Interview 14)

(c2) Illustrative Direct Quotations from Rural Farmers' Interviews

(c2.1) "I … sell wild fruits to urban people… It's hard work, but in season, it brings in extra income… to assist in paying back daily/weekly solar lighting system loans." (Kapiri Interview 7)

(c2.2) "…From Masuku sales, I make between $4 (K100) and $20 (K500) per day during the harvest season, and this income goes a long way in helping with household expenses… solar chargers, solar lighting, …" (Mkushi interview 1)

(c2.3) "Masuku tree numbers are dwindling because some people use them for charcoal burning,… and …cut down… during agricultural land clearing…" (Chongwe Interview 2)

(c3) Illustrative Direct Quotations from Rural Farmers' FGDs

(c3.1) "Wild fruits are a source of strength as they provide the energy we need." (Chongwe FGD 1)

(c3.2) "Wild fruits are liked not just here but by urban people too…. That's why they are sold in every major market in the urban areas" (Chongwe FGD 2)

(c3.3) "Many families pick (Impundu fruits) and process them into a sweet syrup, which is used as a sweetener for porridge. This syrup can be preserved for over a year." (Kapiri FGD 1)

(c3.4) "Edible wild fruits include Masuku (Uapaca kirkiana), Impundu (Parinari curatellifolia), Intugulu (Afromomum africanum), Ifisongole (Strychnos cocculoides), Kawawasha (Tamarindus indica), Imfungo (Anisophyllea boehmii) etc." (Chongwe FGD 2)

(c3.5) "…We consume some, preserve some and sell some to raise some money for salt and sugar." (Kapiri FGD 2)

(c3.6) "Masuku trees drop their fruit when ripe, but Imfungo trees don't, so people cut down the branches of big Imfungo trees to access the ripe fruits. However, Masuku trees are quite brittle… so some people have fallen and gotten injured." (Mkushi FGD 1)

(d) Wild Vegetables and Munkoyo

Wild vegetables and munkoyo serve as essential dietary staples and sources of income for rural households, though their economic returns are modest (d2.5, d3.1).

Traditional vegetables such as bondwe and sope are rich in cultural significance and often used as affordable alternatives to western crops, which are more expensive and sometimes preferred in urban areas (d2.1, d2.2, d2.6). Munkoyo, a popular traditional drink, is harvested extensively, yet overharvesting and deforestation threaten its sustainability (d3.3, d3.5). While beneficial, these resources face challenges including limited profits, environmental degradation, and cultural shifts toward commercialised alternatives (d3.2, d3.5).

(d1) Illustrative Direct Quotations from Commercial Farmers' Interviews

(d1.1) "There are many local wild vegetables available, as well as the leaves of sweet potatoes, pumpkins, cassava, and even beans…sometimes they use pounded peanuts in place of cooking oil. I have tried some of these traditional vegetables, and some are quite nice…" (CF Interview 16)

(d1.1) "I am familiar with the traditional drink, Munkoyo, and have occasionally enjoyed it. Trade Kings Ltd. has made significant profits by commercializing Maheu..." (CF Interview 4)

(d2) Illustrative Direct Quotations from Rural Farmers' Interviews

(d2.1) "Apart from eating kalembula (sweet potato leaves), chibwabwa (pumpkin leaves), katapa (cassava leaves), or chimpapila (bean leaves), I collect wild veggies such as bondwe (Amaranthus), sope (sesamum angustifolium), and the okra-like pupwe (Zanthoxylum chalybeum), as well as kanunka (Bidens pilosa or Melanthera albinerva), which are used as relishes… Sesamum angustifolium, apart from being a relish, has medicinal properties…" (Chongwe Interview 3)

(d2.2) "…Sadly, some people in urban areas tend to shun and look down upon wild veggies, preferring western vegetables instead…" (Mkushi Interview 4)

(d2.3) "Most veggies don't have good profit… Because there are so many farms in the area, we have to travel far to collect the wild veggies." (Mkushi Interview 1)

(d2.4) "I wish I could be ordering chikanda (wild orchid), which is more profitable than these wild veggies that I sell because of poverty. My children have to survive and enjoy even the smallest solar lighting package." (Chongwe Interview 1)

(d2.5) "I am left with no option but to… survive by collecting and selling wild veggies… I have children to feed…, solar lighting loans to settle…" (Kapiri Interview 17)

(d2.6) "…we still eat wild vegetables, but we also like chinese cabbage, rape (kale), spinach, and cabbage, which have overtaken our traditional veggies because they're grown on farms, although they are expensive." (Kapiri Interview 22)

(d2.7) "I sell munkoyo (Rhynchosia venulosa roots) here at home and supply the roots to markets in urban areas... The income might not be much, but it helps to buy some relish…, and sometimes to assist in paying back my solar lighting loan." (Kapiri interview 17)

(d3) Illustrative Direct Quotations from Rural Farmers' FGDs

(d3.1) "I sell wild veggies, but honestly, the income is not much. You need to sell huge volumes just to make a little something…" (Chongwe, FGD 1)

(d3.2) "I sell wild veggies… though it doesn't bring in much, it helps me survive… Things are becoming more expensive, rains are becoming rare, fertiliser is spoiling the soil, forests have been turned into farms, fertiliser is expensive,… fertiliser subsidies have been cut..." (Kapiri FGD 2)

(d3.3) "We dig to get the roots of the munkoyo shrub, which ultimately dies…" (Kapiri FGD 2)

(d3.4) "We are careful to dig pure munkoyo roots and ensure that they are not contaminated with other poisonous roots…" (Chongwe FGD 2)

(d3.5) "Due to excessive harvesting of munkoyo roots, loss of forest, and land clearing for agriculture, the munkoyo shrubs have reduced in number…" (Kapiri FGD 2)

(d3.6) "…we do not buy munkoyo just from any place. We choose carefully… because some people are unhygienic, and others use magic charms to attract customers and get them spiritually addicted to their drink..." (Mkushi FGD 1)

10.6 Discussion and Findings Interpretation

The RUDSHAM framework enriches the discussion by contextualizing solar PV adoption in rural Zambia's socio-economic and environmental landscape. For example, Perceived Ease (PE) and Perceived Usefulness (PU) highlight solar PV's role in supporting honey production, wild fruit processing, and traditional beer brewing. Norms (NO) and Perceived Behaviour Control (PBC) reveal social acceptance and financial flexibility, influencing adoption rates. Economic Cost (EC) and Green Concern (GC) emphasise affordability challenges and environmental sustainability, particularly in wild food harvesting. These attributes collectively inform interpretations on balancing income generation with conservation, emphasizing solar PV's potential for sustainable rural livelihoods. This study, guided by the RUDSHAM framework, reveals a clear relationship between income levels derived from edible NTFPs, sustainability and the adoption of solar PV systems in rural Zambia. Additionally, empirical evidence suggests that individuals with higher incomes, particularly those engaged in ENTFP trade are more likely to afford and invest in advanced solar PV systems.

10.6.1 Wild Honey

The empirical evidence gathered from commercial and rural farmers in Zambia highlights the significant role that wild honey harvesting plays in income generation, while also drawing attention to the associated environmental and social challenges. Honey collection, a key non-timber forest product (NTFP), provides nutritional support and crucial financial benefits for a good number of rural households, particularly in remote regions with limited economic opportunities (Mkushi FGD 2). As observed in the interviews, the sale of 2.5 litres of wild honey for $15 (K300) has enabled farmers to purchase essential items, such as bicycles and household goods, and even repay solar PV lighting loans (Mkushi Interview 3). This aligns with research indicating that wild honey hunting and beekeeping are vital to household incomes in Sub-Saharan Africa, supporting livelihoods and food security (Kalinda and Bwalya, 2014; Lowore, 2020). Additionally, empirical findings highlight that wild honey is in high demand for both dietary and medicinal purposes, which further increases its economic value (Luano interview 4). Similar studies in South Africa have also shown how the commercialization of honey has enhanced household welfare, particularly among women, by providing a steady income source (Taruvinga et al., 2023).

However, the environmental consequences of wild honey harvesting are of major concern. Farmers reported the unsustainable practice of cutting down trees to access honey, particularly when beehives are positioned high in the trees (CF Interview 16,10,11., Kapiri Interview 13, Kapiri FGD 1), which is corroborated by research highlighting how unregulated honey hunting can lead to deforestation and forest fires (Ricketts and Shackleton, 2020). In the Kapiri focus group, respondents noted that these fires often occur when honey hunters use fire to smoke out bees, leading to unintended forest destruction (Kapiri FGD 1). This practice, while economically beneficial in the short-term, jeopardises forest ecosystems and biodiversity, which could have long-term repercussions for communities reliant on forest resources (Mickels-Kokwe, 2006; B. P. Mulenga et al., 2011). Additionally, the drive to meet the growing demand and earn more income has led some households to introduce additives to honey to increase volume which is dangerous especially for innocent people using it for medicinal purposes etc. (Chongwe FGD 2).

Moreover, as farmers compete for honey, the destructive behaviours mentioned also indicate a lack of awareness regarding sustainable harvesting practices (CF Interview 11). This reflects findings from Lowore (2020), who noted the need for improved training and equipment to mitigate environmental harm. To address these challenges, promoting sustainable beekeeping through formal initiatives, such as the introduction of artificial beehives, could help reduce reliance on destructive practices highlighted in Kapiri FGD 1 and supported by the findings of (Ricketts and Shackleton (2020). However, ongoing obstacles, such as insufficient financial support and limited market access, remain key barriers to the sustainable expansion of the honey sector (Hamauswa et al., 2017). The Mkushi farming block farmers association have an organisation called North Swaka Trust (NST) which is a non-profit organisation that aims to restore and protect the natural biodiversity of the North Swaka and Mkushi Headwaters Forest Reserves to better the ecosystem, the livelihoods of the local communities and the businesses that operate in the area (Stone, 2024). The initiative among other things, promotes sustainable bee keeping. Thus, while wild honey collection offers substantial economic benefits, achieving a balance between income generation and environmental preservation requires increased investment in sustainable practices and broader conservation efforts.

10.6.2 Traditional Beer

The integration of self-financed solar photovoltaic (PV) systems in rural Zambia has multifaceted environmental and social implications, particularly in relation to traditional beer production, a prominent source of income for some rural households. Traditional beer production, primarily led by women, has contributed significantly to household income, enabling investments in essential goods such as solar PV lighting systems, roofing materials, and mobile phones (Chongwe Interview 2). This mirrors the broader trend in sub-Saharan Africa, where traditional beer plays a crucial role in rural economies, offering a sustainable livelihood for many, especially in regions with limited formal employment opportunities (Sawadogo-Lingani et al., 2021). Despite these economic benefits, the commercialization of traditional beer raises important concerns, including adverse social and environmental consequences, as observed both in the empirical evidence and existing literature.

From a social perspective, alcohol abuse has become a pervasive issue in rural communities, exacerbated by the accessibility of traditional beer, particularly potent variants like “kachasu”. This has led to increased incidents of domestic violence, criminal activity, and the spread of sexually transmitted infections (STIs), including HIV, as evidenced by interviews with local farmers (Chongwe FGD 1; Mkushi Interview 4). Similar patterns of alcohol-induced social disruption have been documented in other sub-Saharan regions, where traditional alcohol consumption has been linked to heightened sexual risk behaviours and increased HIV transmission (Rich et al., 2015). The economic dependency on beer production, while providing short-term gains, poses long-term risks to community health and social stability, as alcohol expenditure often detracts from critical household needs such as food security (Paltzer et al., 2021).

Environmentally, the production of traditional beer also presents significant challenges. The brewing process, which often involves the use of locally sourced grains, can lead to the overexploitation of agricultural resources and environmental degradation, a trend seen in other industries such as charcoal production (Gumbo et al., 2013). Additionally, health risks related to poor brewing practices are prevalent. As highlighted in Kapiri FGD 1, some brewers introduce chemical catalysts to expedite fermentation, potentially leading to the presence of harmful toxins. The contamination of local water systems and grains, as observed in similar cases in Tanzania and Zambia, underscores the urgent need for improved brewing and storage practices to mitigate public health risks (Kachapulula et al., 2017; Ministry of Information, 2024).

10.6.3 Wild Fruits

The interplay between self-financed solar photovoltaic (PV) systems and the commercialization of edible non-timber forest products (NFTPs) such as wild fruits in rural Zambia presents both opportunities and challenges. Edible wild fruits, including Masuku [Uapaca kirkiana], Impundu [Parinari curatellifolia], and Intugulu [Afromomum africanum], have emerged as essential resources for rural households, contributing significantly to income and food security. This aligns with literature indicating that wild fruits comprise approximately 80% of the total fruit intake in rural Zambian households (Ickowitz1 et al., 2021). Farmers have reported earnings of between $4 US (K100) and $20 US (K500) per day from the sale of fruits during peak seasons, which provides critical support for household expenses such as school uniforms, airtime, and solar PV lighting loans (Mkushi Interview 1; Kapiri Interview 7).

However, the economic benefits associated with these wild fruits are counterbalanced by sustainability concerns. For example, Imfungo [Anisophyllea boehmii] trees sometimes badly damaged to access the fruits on big trees (Mkushi FGD 1). Additionally, interviewees noted the declining numbers of wild fruit tree due to practices such as charcoal production and agricultural land clearing (Chongwe Interview 2). This trend echoes findings that highlight the overharvesting of wild fruits driven by economic incentives, which threatens biodiversity and ecosystem stability (Hudson et al., 2020; Murye and Pelser, 2018). The interplay of economic pressures and environmental degradation raises a critical question regarding the sustainability of these resources. While the commercialization of wild fruits could potentially enhance rural economies, it necessitates the implementation of sustainable harvesting practices to prevent further depletion of vital species.

Local farmers also highlighted the socio-cultural value of wild fruits, describing them as "a source of strength," especially during labour-intensive activities such as farming (Chongwe FGD 1). This aligns with existing literature that emphasises the nutritional and medicinal significance of edible NFTPs in rural diets (Mutelo et al., 2022). Furthermore, the processing of Impundu fruits into syrup for preservation underscores the value of wild fruits in enhancing food security, as households can store them for extended periods (Kapiri FGD 1). Nonetheless, barriers to sustainable income generation persist, including health risks from aflatoxin contamination in certain fruit species, which complicates market participation (Kachapulula et al., 2019). The lack of community-based management systems and regulatory frameworks further exacerbates these challenges, limiting the effectiveness of conservation efforts (Anyango et al., 2018).

10.6.4 Leafy Vegetables and Tubers

The integration of income-financed solar photovoltaic (PV) systems in rural Sub-Saharan Africa highlights the complex relationship between environmental sustainability and income generation through the use of natural resources. In Zambia, wild vegetables, tubers, and munkoyo roots have traditionally provided rural households with essential dietary nutrients and supplemental income. Empirical evidence reveals that these resources serve as both a subsistence strategy and a vital means of income, particularly in economically constrained areas where solar PV lighting costs are financed through low-income sources like the sale of these natural products (Chongwe Interview 3; Kapiri Interview 17).

Households collecting wild vegetables and tubers benefit significantly from their consumption and potential sales, with wild vegetables like Amaranthus, Sesamum angustifolium, and Bidens pilosa used frequently as food and sold for income. However, despite their contributions, interview data from the Kapiri and Mkushi regions show that income generated from selling wild vegetables is often inadequate relative to the labour involved (Mkushi Interview 1; Kapiri FGD 2). This finding aligns with literature indicating that wild vegetables in sub-Saharan Africa are often stigmatised as "food for the poor," undermining their commercial potential (Mercy et al., 2017; Qwabe and Pittawaty, 2023). Furthermore, access to these resources is increasingly constrained due to deforestation and agricultural expansion, which drives harvesting efforts further from settlements (Steel et al., 2022., Kapiri FGD 2).

The economic benefits of selling wild products remain marginal, typically yielding limited income that covers basic household needs but fails to provide substantial financial uplift. For instance, a significant proportion of rural Zambian households, approximately 86% and 73%, engage in the collection of wild vegetables and tubers, respectively (Steel et al., 2022), yet empirical accounts suggest that sales rarely exceed minimal earnings (Chongwe FGD 1). However, the cash flow from even these minor transactions supports essential expenses, such as contributions toward household energy costs through solar PV lighting loan repayments (Kapiri Interview 17; Chongwe Interview 1). The low financial returns are compounded by consumers' negative perceptions, where wild foods are less preferred than Western vegetables, impacting rural vendors' profitability (Mkushi Interview 4., Qwabe & Pittawaty, 2023).

Environmental impacts of wild product collection are another concern. Excessive harvesting and forest clearing have reduced the availability of key species like the munkoyo shrub (Rhynchosia venulosa), which, due to its importance for local beverages, faces sustainability challenges (Kapiri FGD 2., Steel et al., 2022)). Literature echoes these challenges, citing overharvesting, biodiversity loss, and unsustainable land use practices as significant risks to the wild edible plant ecosystem (Murye and Pelser, 2018; Pitso and Lebese, 2014). Furthermore, with the collection of 380 million litres of wild food annually, there is considerable strain on forest resources that serve multiple ecological roles (Steel et al., 2022). For instance, Kalaba et al. (2009) documented the extensive degradation of Zambian forests and corresponding biodiversity declines, requiring stakeholders to travel longer distances for collection (Steel et al., 2022).

Efforts to promote the conservation and sustainable use of wild vegetables and other plant species are crucial. Researchers have noted the importance of supporting the formal cultivation and market development for indigenous species to alleviate pressure on wild populations and improve income prospects for rural communities (Arumugam et al., 2020; Ochieng et al., 2019). Additionally, fostering local awareness about the nutritional value and environmental benefits of indigenous plants could mitigate social stigma and bolster both consumption and commercial demand, providing a pathway to enhance food security and income stability in these communities (Mungofa et al., 2018; Qwabe and Pittawaty, 2023).

10.7 Recommendations for Policy and Practice

Transitioning to self-financed solar photovoltaic (PV) systems in rural Zambia presents an opportunity to enhance energy access while addressing environmental and social challenges linked to edible non-timber forest products (ENTFPs). Key recommendations for fostering sustainable solar PV adoption, leveraging local income from ENTFPs, are outlined below.

10.7.1 Sustainable Beekeeping and Market Development

The Ministry of Green Economy and Environment, in collaboration with the Forestry Department and NGOs such as North Swaka Trust (NST), should facilitate the adoption of artificial beehives and sustainable honey harvesting techniques. Financial incentives and training programmes should be introduced to support rural beekeepers in reducing deforestation caused by destructive harvesting methods. Additionally, partnerships with private sector actors like Zambezi Gold Honey Ltd. can help expand market access, ensuring rural farmers receive fair prices for sustainably harvested honey. Government-backed certification schemes could enhance the credibility of sustainably sourced honey, increasing demand both locally and internationally.

10.7.2 Beer Regulation and Health Awareness

The Ministry of Health, in partnership with the Ministry of Local Government and Rural Development, should implement regulatory frameworks that address the health risks associated with informal beer brewing. Training programmes should be conducted in rural communities to promote safe brewing practices and prevent the use of harmful additives. NGOs such as the Zambia Association for Public Health (ZAPH) can support awareness campaigns on responsible alcohol consumption and its social implications. Simultaneously, microfinance initiatives could offer alternative income sources, reducing economic dependency on beer production while mitigating public health concerns.

10.7.3 Community-Based Fruit Conservation Programmes

The Ministry of Agriculture and the Department of National Parks and Wildlife should collaborate to develop community-led wild fruit conservation programmes. Encouraging agroforestry and sustainable harvesting methods will prevent ecosystem degradation. Organizations like the Zambia Forestry and Forest Industries Corporation (ZAFFICO) and the Worldwide Fund for Nature (WWF) Zambia can provide technical support and funding for reforestation efforts targeting endangered wild fruit species. Additionally, integrating wild fruits into formal agricultural value chains could boost rural economies, with cooperatives linking small-scale harvesters to urban markets and export opportunities.

10.7.4 Indigenous Vegetables and Market Integration

The Ministry of Agriculture, in partnership with Zambia Agricultural Research Institute (ZARI) and the Food and Agriculture Organization (FAO), should promote the cultivation of indigenous vegetables through seed distribution programmes and farmer training initiatives. Enhancing the commercial appeal of traditional vegetables requires consumer awareness campaigns emphasizing their nutritional and economic value. Additionally, partnerships with retailers like Shoprite and local agribusinesses could facilitate the integration of wild vegetables into mainstream markets. Expanding irrigation and storage infrastructure will also enhance productivity, ensuring rural farmers can sustainably scale up indigenous vegetable production.

10.7.5 Legal Frameworks for Forest Protection

The Ministry of Lands and Natural Resources, together with the Zambia Environmental Management Agency (ZEMA), should strengthen policy enforcement to curb deforestation linked to wild food harvesting. The introduction of community forest management agreements can empower local groups to oversee resource conservation while benefiting from sustainable economic activities. International development partners such as the United Nations Development Programme (UNDP) and the African Development Bank (AfDB) can support financing mechanisms that incentivise rural households to engage in eco-friendly livelihood practices. Additionally, digital monitoring systems using satellite imagery can track deforestation trends, ensuring timely interventions.

10.8 Conclusion and Contribution to Knowledge

10.8.1 Summary of Key Findings

This study highlights the crucial role of edible non-timber forest products (ENTFPs) in financing solar photovoltaic (PV) adoption among rural Zambian households. Wild honey, traditional beer, wild fruits, and leafy vegetables contribute significantly to income but pose environmental risks such as deforestation and biodiversity loss. Social concerns, including alcohol abuse and unsustainable harvesting, further complicate the benefits. While ENTFPs enable solar access, balancing economic gains with sustainability remains a challenge. Strengthening conservation efforts, promoting sustainable harvesting, and improving market accessibility are essential for ensuring long-term environmental and socio-economic stability in rural communities.

10.8.2 Contribution to Knowledge

This research advances understanding of rural electrification by linking solar PV adoption with ENTFP-based income. It demonstrates how rural households leverage natural resources to finance decentralised energy solutions while navigating economic and ecological constraints. The study enriches the discourse on informal financing mechanisms for solar access, emphasizing the trade-offs between income generation and environmental sustainability. Findings provide insights for policymakers and practitioners seeking to enhance rural energy transitions through context-specific strategies that align economic development with conservation priorities. This research informs future interventions promoting sustainable rural livelihoods through renewable energy adoption.

10.8.3 RUDSHAM's Novel Contribution Introduced

The RUDSHAM framework offers a novel approach to analysing solar PV adoption within rural, resource-dependent communities. It integrates socio-economic and environmental factors, providing a structured tool for assessing the viability of decentralised energy solutions. By contextualizing the motivations, barriers, and sustainability concerns of solar adoption, RUDSHAM advances the theoretical understanding of rural energy transitions. Its application extends beyond Zambia, offering a framework adaptable to similar settings globally. The framework's novelty lies in its comprehensive perspective, guiding policymakers, researchers, and development practitioners in designing interventions that align energy access with sustainable natural resource management.

10.8.4 Future Research Directions

Longitudinal studies assessing the long-term socio-economic and environmental impacts of ENTFP-driven solar adoption are needed. Investigating market development strategies, including value addition and certification for ENTFPs, could enhance economic opportunities. Additionally, analysing regulatory frameworks and policy influences on ENTFP commercialisation and solar adoption would strengthen sustainability efforts in rural electrification.

10.8.5 Study Limitations and Future Research

Future studies should expand geographical scope, integrate multi-method approaches, and assess technological innovations that support both energy access and environmental conservation. Addressing these limitations will enhance understanding and inform more effective rural development strategies. strategies.

Chapter 11: Environmental and Social Impacts of Self-Financed Solar PV: Insights from Mopane Worms, Mushrooms, Fishing, Bushmeat and Ethnomedicine (Article 7)

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Summary: This article investigates how self-financed solar photovoltaic (PV) adoption in rural Zambia is interlinked with the harvesting and sale of non-timber forest products (NTFPs), including Mopane worms, mushrooms, bushmeat, fish, and ethnomedicine. These resources are central to both household consumption and cash generation. The study focuses on the dual role of NTFPs as enablers of solar PV investment and as elements under ecological threat due to overexploitation.

Abstract: The research highlights a key paradox: while NTFPs provide essential income that facilitates solar PV adoption, thus reducing reliance on charcoal and enhancing energy equity, their increased commercialisation exacerbates habitat degradation, biodiversity loss, and intra community tensions. Although households report improved wellbeing through access to lighting, mobile phone charging, and extended working hours, this comes at the cost of environmental strain and resource competition, particularly in areas lacking regulatory oversight.

Recommendations: Key recommendations include integrating solar energy and natural resource governance policies, promoting sustainable harvesting practices, and fostering local governance structures for resource monitoring. Encouraging alternative livelihoods and community-led conservation can mitigate the negative impacts of NTFP overuse while sustaining the benefits of energy access.

Overall contribution: This article addresses Thesis Objectives 1 and 5 by offering detailed insights into the environmental trade-offs and livelihood dynamics associated with rural solar energy transitions. It complements Article 6 by expanding the analysis to include a broader set of NTFPs, reinforcing the thesis’s central argument that energy sustainability in Sub-Saharan Africa must be embedded in ecological and socio-cultural realities.

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11.1 Introduction and Background

Zambia, like many Sub-Saharan African (SSA) nations, faces critical energy access challenges, particularly in rural regions where only 14.5% of households have electricity, leaving over 12 million people without access (Kapole et al., 2023). This lack of electrification perpetuates poverty and limits socio-economic development, healthcare, and education (Hafner et al., 2018; Olatomiwa et al., 2022). Zambia relies heavily on hydropower for over 85% of its energy supply, but recurrent droughts exacerbate load-shedding, with outages lasting up to 21 hours daily (ERB Report, 2023; ZESCO, 2024). By the third quarter of 2024, residential electricity in some areas was limited to three hours daily (ZESCO, 2024b), highlighting the urgency of diversifying the energy mix to ensure resilience against climate variability.

Renewable energy technologies, particularly solar photovoltaic (PV) systems, provide a sustainable solution to energy poverty. With over 3,000 hours of annual sunlight, Zambia possesses vast solar potential (Chambalile et al., 2024). Solar PV systems can bypass grid limitations, delivering power for lighting, irrigation, and mechanization, while reducing reliance on biomass fuels, lowering CO_2 emissions, and improving air quality (Adjei, 2024; Byaro et al., 2024). Despite declining global solar costs, adoption in Zambia remains low, contributing just 3.23% to the energy mix (Chambalile et al., 2024). High poverty levels and a $0.83/kWh levelised solar electricity cost, the highest globally, render solar PV unaffordable for many rural households, 36% of whom cannot transition from traditional fuels (Baurzhan & Jenkins, 2016; Szabó et al., 2021). Self-financing models offer a promising solution to address financial barriers, allowing incremental solar PV investments and reducing energy costs by up to 46% (Mukisa et al., 2022; Tinta et al., 2023). Solar PV systems also stimulate rural economies, create jobs, and support Zambia's climate mitigation goals by curbing deforestation and biomass dependence (Ezeh et al., 2023; Makai & Daniel Chowdhury, 2017). However, socio-economic disparities and high upfront costs necessitate supportive policies to maximise adoption benefits (Agoundedemba et al., 2023; Bhattacharyya and Palit, 2021).

Non-timber forest products (NTFPs) such as Mopane worms, mushrooms, bushmeat, and ethnomedicine, provide essential income for rural Zambians, contributing 32-35% of household incomes (Mulenga et al., 2011; Steel et al., 2022). Approximately 100% of rural households harvest fruits, while 86% collect mushrooms and leafy vegetables, and 82% rely on insects for sustenance and income (Steel et al., 2022). NTFPs bridge seasonal financial gaps, enabling households to invest in solar PV systems (Shackleton et al., 2024; Timko et al., 2010). However, unsustainable harvesting practices, including overhunting and excessive wild fruit collection, threaten biodiversity and forest ecosystems (Anyango et al., 2018). To address these challenges, conservation strategies such as scientific harvesting and community-based resource management are critical for balancing economic needs with environmental protection (Derebe and Alemu, 2023).

By integrating solar PV adoption with sustainable NTFP management, Zambia the potential to address rural energy access and environmental degradation simultaneously. This synergistic approach promotes socio-economic development while safeguarding ecosystems, providing a replicable model for SSA (Amadu and Miller, 2024; Shackleton and Shackleton, 2014).

11.1.1 Research Problem

- There are currently insufficient insights into solar PV adoption in rural Zambian households:
- The immediacy of potential adverse environmental and societal effects of income from edible NTFPs:
- The need to critically assess the viability, benefits, and limitations of financing mechanisms.

11.1.2 Research Objectives

- To analyse the link between rural household NTFP income and solar PV adoption:
- To investigate available financing mechanisms for solar PV systems in rural Zambia: and
- To assess environmental and societal impacts of current income-generating activities tied to NTFPs.

11.1.3 Research Questions

- What financing mechanisms from edible NTFPs support (or hold the potential to support) solar PV adoption in rural Zambia?
- What are the advantages and challenges of those mechanisms?
- How do those mechanisms affect the adoption and sustainability of solar PV systems?
- What are the environmental and societal effects of income-generating activities from NTFPs?

11.1.4 Research Gap and Contribution

The relationship between solar photovoltaic (PV) adoption in rural areas and income derived from NTFPs has not been extensively studied, particularly in the context of Sub-Saharan Africa. This study uniquely addresses this gap by applying the novel Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM) to examine how income from NTFPs facilitates self-financed solar PV adoption in rural Zambia. It is the first research to focus on the specific role of five key NTFPs, Mopane worms, mushrooms, fishing, bushmeat, and ethnomedicine, in enabling solar PV adoption, while simultaneously exploring the environmental and socio-economic consequences of this dynamic.

As global efforts intensify to promote renewable energy adoption, it is vital to understand the financing methods rural households employ to afford solar PV systems. This study highlights how NTFPs, while providing vital income streams for solar PV investments, can also create environmental pressures such as overharvesting, habitat degradation, and biodiversity loss, alongside potential risks to rural food security. Its findings and recommendations contribute to the broader discourse on energy access and sustainability by offering actionable insights for policymakers, aid agencies, and stakeholders. It stresses the need for integrated solutions that simultaneously promote renewable energy adoption, sustainable resource management, and rural food security. By identifying strategies that balance energy transitions with environmental conservation, this research offers a replicable framework for addressing energy poverty and ecological sustainability in similar rural contexts globally.

11.2 Literature Review

This literature review evaluates income-generating activities linked to NTFPs in rural Zambia, specifically Mopane worms, mushrooms, fishing, bushmeat, and ethnomedicine. These activities provide significant economic and nutritional benefits but pose environmental and social challenges, particularly within the context of financing self-sustained solar photovoltaic (PV) systems.

11.2.1 Mopane Worms

Mopane worms, a key source of nutrition and income in rural Zambia, are rich in protein and play an essential economic and societal role, particularly for women and unemployed individuals. Annual regional harvests of 9.5 billion caterpillars underline their economic importance, enabling marginalised households to meet basic needs (D'Souza & Govender, 2019; Hlongwane et al., 2021; Togarepi et al., 2020). However, unsustainable harvesting and climate change threaten their populations, with up to 70% of their habitats projected to disappear by 2080 due to land-use changes (Shen et al., 2023). Sustainable harvesting practices and local governance are necessary to protect this income stream and maintain ecosystem stability (Ndlovu et al., 2019; Sekonya et al., 2020).

11.2.2 Wild Mushrooms

Wild mushrooms serve as both a dietary supplement and a valuable income source, particularly for communities reliant on forest resources. Species like Amanita loosii hold high market value, supporting rural economies (Mlambo and Maphosa, 2017; Rookmaaker, 2020). Yet, forest degradation and overharvesting, often due to weak regulations, endanger these ecosystems and exacerbate biodiversity loss (Sileshi et al., 2023; Steel et al., 2022). Foraging practices remain largely unsustainable, stressing the importance of integrating ecological preservation strategies into local governance (Anyango et al., 2018; Zulu et al., 2019).

11.2.3 Ethnomedicine

Ethnomedicine is central to healthcare and livelihoods in Zambia, with approximately 70% of the population relying on traditional remedies. Ethnoveterinary practices aim further to support rural wellbeing, especially in areas lacking formal healthcare (Eiki et al., 2021; Muyenga et al., 2018). Medicinal plants, for example, generate up to 58% of annual household income in some cases, highlighting their economic potential (Timmermann and Smith-Hall, 2019). However, overexploitation and supply chain inefficiencies limit sustainable commercialization. Policies incorporating traditional knowledge and sustainable harvesting training are essential for balancing economic benefits with biodiversity conservation (Fandohan et al., 2017; Meke et al., 2017).

11.2.4 Bushmeat

Bushmeat serves as a critical protein source and income generator for rural households. Initiatives like sport hunting provide substantial economic benefits, distributing over 129,000 kilograms of game meat annually (White and Belant, 2015). During periods of food scarcity, bushmeat trade acts as a financial safety net (Stone and Stone, 2022). However, unsustainable hunting near protected areas threatens wildlife populations, while increasing zoonotic disease risks, including Ebola and HIV (Gonçalves et al., 2019; Kurpiers et al., 2015). Policies promoting sustainable hunting practices and addressing poverty are crucial to mitigate ecological and health impacts (Sakala, 2016).

11.2.5 Wild Fishing

Fishing provides critical sustenance and income, especially in areas like Luapula Province, where fish is a dietary staple. Almost all rural households engage in fishing related activities, highlighting its significance for food security and economic stability (Marinda et al., 2023; Steel et al., 2022). However, overfishing, inadequate infrastructure, and destructive techniques such as water poisoning degrade aquatic ecosystems and diminish fish stocks (Tweddle et al., 2015). Enhancing women's participation in fisheries and improving access to credit and markets are vital for long-term sector sustainability (Muzari and Muzari, 2013; Temesgen et al., 2019).

11.2.6 Witch Doctor Practices

Traditional healing practices provide critical healthcare services and income in underserved areas. However, these practices also perpetuate what some observers have characterised as harmful beliefs, fostering fear and deepening social divisions (Eiki et al., 2021a; Gershman, 2016). Extreme manifestations, such as ritual killings, exacerbate poverty and instability, particularly in marginalised communities (Mwiba, 2018; Steyn, 2022). Addressing these issues requires community education and governance mechanisms to curb harmful practices while preserving their income potential.

From the literature review, it is evident that while NTFPs undeniably support rural livelihoods substantially and enable solar PV financing, their unsustainable exploitation expose some considerable ecological and social risks. Addressing these challenges requires integrating sustainable management practices with inclusive policies to balance economic development, environmental conservation, and social equity.

11.2.7 NTFP Management Case Studies

Non-timber forest products (NTFPs) are vital for rural livelihoods and play a critical role in forest conservation across Africa. Case studies highlight the economic and ecological benefits of NTFPs, emphasising the importance of indigenous knowledge and sustainable harvesting practices in improving forest and tree based ecosystem management (Amusa et al., 2024). Successful examples include the commercialization of baobab fruit in South Africa and Malawi and the sustainable harvesting of golden grass in Brazil, demonstrating the potential for NTFPs to provide income while conserving biodiversity (Shackleton, 2015). Underutilised categories such as edible insects and mushrooms are gaining recognition for their ability to alleviate food insecurity and reduce the environmental footprint of food production. Their sustainable management within Africa's multifunctional landscapes offers promising pathways for economic and environmental resilience (Amusa et al., 2024). Additionally, the Action Against Desertification project promotes sustainable harvesting of products like gum arabic, honey, and Balanites oil, further exemplifying the potential of NTFP-based livelihoods in fostering rural development and conservation (Bernhard, 2019).

11.2.8 Challenges of Solar Financing Using Forest Products

The NTFP income to finance solar PV systems in rural African communities is fraught with several risks and challenges. Financially, NTFP income is highly volatile due to seasonal availability and market demand, leading to inconsistent funding for solar projects (Adelhardt and Berneiser, 2024). The high initial costs of solar PV systems further exacerbate this challenge, as they often exceed the financial capacity of rural households reliant on NTFP income (Baurzhan & Jenkins, 2016; Soboyejo & Otiti, 2006). Regulatory barriers, including inadequate policies and dependency on international subsidies, hinder the establishment and sustainability of solar projects (Adelhardt & Berneiser, 2024; Baurzhan & Jenkins, 2016). Furthermore, rural communities often lack the technical expertise required to maintain solar systems, leading to operational failures (Utoh et al., 2024). Solar PV systems may also fail to meet the energy demands of critical activities like agro-processing, which are vital for rural economic development (Otiti and Soboyejo, 2006). Additionally, NTFP enterprises themselves face challenges such as poor marketing, transportation difficulties, and regulatory obstacles, which limit their capacity to generate stable income (Kunwar et al., 2009; Yusuff, 2014). Addressing these risks requires government investment in rural infrastructure, improved market access, and civil society involvement to influence supportive policies (Kunwar et al., 2009; Yusuff, 2014).

11.2.9 Solar PV Financial Models in Rural Areas

Figure 41: Financing Models compiled by author.

Financing Model	Cost-Efficiency	Scalability	Community Impact	Sustainability	Environmental Impact	Advantages	Disadvantages
1. Pay-As-You-Go (PAYG)	High cost-efficiency for low-income users, as small instalments reduce financial barriers.	Highly scalable due to mobile payment technology and widespread adoption of off-grid systems.	Provides affordable energy access, reduces reliance on kerosene, and improves household health.	Sustainable if default rates are low and payment mechanisms are robust.	Reduces deforestation and carbon emissions by replacing kerosene and wood fuels.	Affordable for low-income households; accessible via mobile technology.	May not be sustainable in areas without reliable mobile money networks or low-income regions with payment defaults.
2. Microfinance Loans	Moderately cost-efficient, as small interest rates spread costs over time.	Scalable in areas with established microfinance institutions.	Empowers women and small entrepreneurs, fostering rural development and energy access.	Sustainable if repayments are regular and institutions are well-managed.	Reduces reliance on polluting fuels, indirectly conserving natural resources.	Encourages entrepreneurship and economic development; flexible repayment terms.	Requires strong financial institutions; interest rates can vary, burdening borrowers in some cases.
3. Government Subsidy Programmes	Very cost-efficient for users, as governments bear most of the initial cost.	Limited scalability, often depending on government budgets and political will.	Expands access to energy for underserved populations, benefiting households and public facilities.	Sustainable only with well-targeted subsidies and phased-out plans for market independence.	Reduces dependency on wood fuel but risks inefficiency if poorly managed.	Reduces costs significantly for rural households; can stimulate adoption quickly.	Risk of dependency on subsidies; implementation can be delayed due to bureaucratic processes.
4. Community-Owned Cooperatives and village banking.	Long-term cost-efficiency, as profits are reinvested into local energy projects and community initiatives.	Moderately scalable; requires strong community organisation and governance structures.	Enhances community ownership, creating jobs and fostering local pride in energy solutions.	Highly sustainable if communities are empowered to manage operations effectively.	Promotes clean energy adoption and protects natural ecosystems through local stewardship.	Strengthens local decision-making and economic resilience; creates a sense of ownership.	Initial organisation can be challenging; requires effective leadership and management skills at the local level.
5. Income from Non-Timber Forest Products (NTFPs)	Moderately cost-efficient, as NTFP-derived income (e.g., honey, fruits) offsets solar system costs.	Limited scalability; depends on sustainable forest management and availability of resources.	Supports rural livelihoods and self-financing of energy systems while promoting economic independence	Sustainable if NTFPs are harvested responsibly to avoid resource depletion.	Reduces deforestation when managed sustainably; integrates conservation with development.	Encourages self-reliance; aligns energy goals with forest conservation efforts.	Vulnerable to overexploitation and climate impacts on forest productivity; limited to areas with rich forests.
6. Private-Sector Mini-Grids	Moderate cost-efficiency; higher upfront costs but cost-efficient in clustered rural areas.	Highly scalable with supportive policies and private investment incentives.	Provides reliable electricity for entire villages or clusters, fostering economic and social development.	Sustainable if backed by long-term policies, financial viability, and community engagement.	Reduces greenhouse gas emissions and protects local environments.	Reliable and efficient for clustered rural areas; can support small businesses and public facilities.	Requires significant capital investment; may face challenges in regulatory and licensing frameworks.

11.3 Theoretical Framework to Inform the Study

The current study introduces and employs the novel Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM) (see Fig. 42) to help explain and interpret the extent to which self-financed solar PV systems in rural areas of Africa impact rural society and the environment. RUDSHAM integrates three main theoretical frameworks to understand the factors influencing the adoption of renewable energy technologies in rural areas. It combines the Technology Acceptance Model (TAM), Diffusion of Innovations Theory (DOI), and Theory of Planned Behaviour (TPB) to focus on internal factors affecting adoption willingness. TAM highlights performance expectancy, effort expectancy, social influence, and facilitating conditions as key drivers of technology adoption (Ajzen, 1991; Davis, 1989; Rogers, 2003a; Venkatesh and Davis, 2000). Diffusion of Innovations Theory explains the stages and factors influencing the spread of new technologies over time (Rogers, 2003b). TPB suggests that behavioural intentions are shaped by attitudes, subjective norms, and perceived behavioural control (Ajzen, 1991). Additionally, RUDSHAM incorporates Social Learning Theory (SL), which emphasises the role of observation and imitation in shaping attitudes and adoption decisions (Bandura, 1977). Social dynamics, such as peer effects and active communication within social networks, significantly influence individuals' decisions to adopt renewable energy technologies.

By combining internal factors from TAM, DOI, and TPB with external influences from Social Learning Theory and peer effects, RUDSHAM offers a comprehensive understanding of the multifaceted factors driving renewable energy adoption in rural developing areas. This holistic approach recognises the complex interplay between individual beliefs, social influences, and community dynamics in shaping adoption behaviours. The framework provides valuable insights for policymakers, researchers, and practitioners aiming to promote sustainable energy transitions. RUDSHAM's alignment with a mixed methods research approach, including in-depth interviews, focus groups and observations, ensures a thorough examination of solar PV adoption in rural Zambia. This integration of theoretical and methodological rigour offers a robust foundation for investigating the complex factors impacting solar PV adoption, facilitating the development of effective strategies for sustainable energy development.

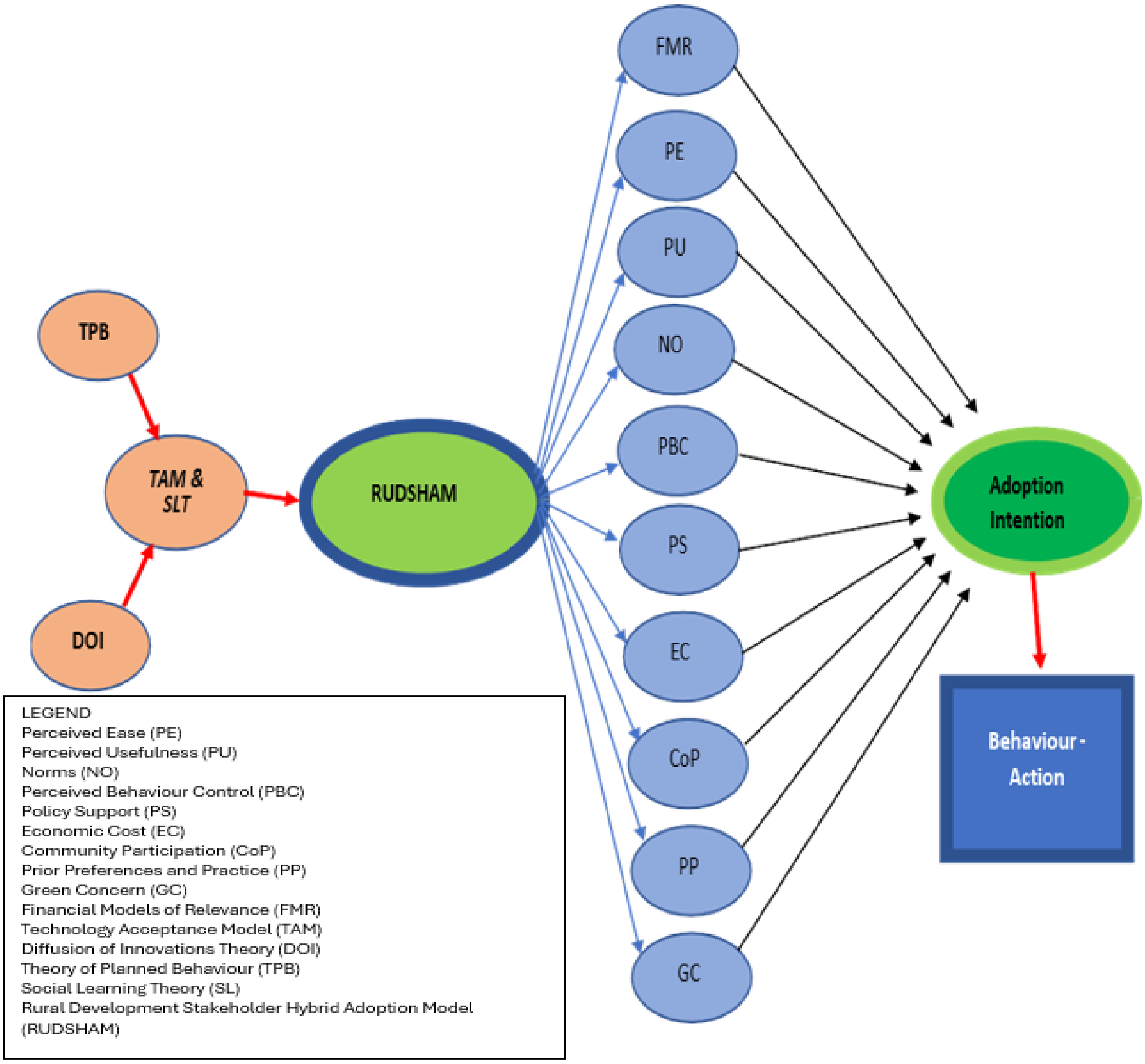

Figure 42: RUDSHAM Hybrid Adoption Model

The Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM) is suitable for analysing the environmental and social impacts of self-financed solar PV systems in rural Zambian rural households. By integrating perceived ease, usefulness, social norms, and behaviour control, RUDSHAM captures key factors influencing adoption. Policy support, economic cost, and community participation contextualise the socio-economic environment, while green concern and financial models highlight sustainability and financing challenges. The framework's comprehensive approach aligns with assessing energy access, sustainability, and rural livelihoods, offering a valuable theoretical lens to understand household decision-making in the context of solar PV systems adoption. For details on the description of how each attribute of the RUDSHAM framework assisted, refer to Appendix B.

11.4 Research Methodology

The study was conducted over six months, from October 2022 to March 2023, across three remote rural areas in Zambia: Mkushi Rural (Central Province), Kapiri Rural

(Central Province), and Chongwe Rural (Lusaka Province) (see Fig. 43). These areas were purposively selected due to their relative isolation and lack of access to the national power grid. A multi-stage sampling approach was employed. In the first stage, Mkushi, Kapiri, and Chongwe were purposively selected for their geographical and infrastructural characteristics. In the second stage, participants for focus group discussions (FGDs) and interviews were selected using non-probability sampling techniques. Specifically, convenience sampling was used for FGDs, and purposive sampling was applied to select key informants and stakeholders. A four-week pre-testing pilot study involving five participants from Luano village (Chingola Rural, Copperbelt Province) was conducted to ensure the validity and reliability of the research instruments. Data collection was facilitated by one research assistant fluent in English and multiple local languages (Bemba, Tonga, Soli, Lamba, and Nyanja), alongside the primary investigator, who is fluent in English and has working knowledge of Bemba, Nyanja, and Lamba.

The primary data collection methods included in-depth interviews and focus group discussions. A total of 40 rural farmers, 16 commercial farmers, and 3 key stakeholders from solar energy companies and government policymaking institutions were interviewed, with interview durations ranging from 30 to 60 minutes. Seven FGDs were conducted, including three in Kapiri, two in Mkushi, and two in Chongwe. Each group comprised 8 to 12 participants, ensuring diverse perspectives. Gender-sensitive practices were incorporated by organizing mixed and separate FGDs for men and women, facilitated by village headmen or councillors to foster trust and mitigate dominance issues. Participants received refreshments and tokens of appreciation for their involvement. Recorded interviews and photographs, taken with consent, were securely stored on the University's OneDrive cloud account with protected access to ensure data security. Data analysis employed NVIVO 14 to enable methodological integrity and systematically analyse findings derived from the RUDSHAM framework. Interview transcripts and focus group discussions were coded into themes, using both colour-coding techniques and NVIVO's advanced analytical tools to identify patterns and insights. NVIVO facilitated the organisation of data related to RUDSHAM attributes, including Perceived Usefulness, Policy Support, and Community Participation. This approach ensured robust thematic analysis, enhancing the study's credibility and reliability.

Figure 43: Map of Zambia. Map sources 2022

11.5 Research Findings

The RUDSHAM framework's attributes facilitated the comprehensive gathering of findings in the study. Each attribute guided specific data collection efforts, producing a range of important insights. Perceived Ease (PE) revealed challenges in solar PV installation, maintenance, and support accessibility. Perceived Usefulness (PU) highlighted solar PV's role in improving livelihoods, reducing energy insecurity, and enhancing productivity. Norms (NO) examined societal acceptance and the influence of peer networks on adoption. Perceived Behaviour Control (PBC) assessed consumer confidence through warranties, system flexibility, and choice availability. Policy Support (PS) identified government subsidies and supplier roles in overcoming barriers. Economic Cost (EC) clarified affordability perceptions and energy expenditure impacts. Community Participation (CoP) explored local ownership, supplier engagement, and sustainability factors. Prior Preferences and Practice (PP) contextualised the transition from traditional energy sources. Green Concern (GC) connected environmental awareness to solar PV adoption motivations, while Financial Models of Relevance (FMR) compared global financing models with local practices, offering scalable pathways. Together, RUDSHAM produced holistic results, linking socio-economic, environmental, and cultural factors to solar PV adoption in Zambia.

11.5.1 Rural Income via RUDSHAM Evidence

(a) Mopane Worms (Edible Caterpillars)

The narratives reveal conflicting perspectives on Mopane worm harvesting, highlighting its socio-economic benefits and environmental challenges. Rural farmers emphasise its economic importance, noting that it provides a critical income source, often surpassing agriculture (a2.1, a2.4, a3.1), despite dangers and declining worm populations due to overharvesting (a2.2, a2.6, a3.6). In contrast, commercial farmers express concern over deforestation and unsustainable practices, citing aggressive collectors cutting down key host trees (a1.1, a1.2, a1.5, a3.6). Governance issues exacerbate tensions, with collectors bribing authorities (a1.6) and ignoring traditional controls once enforced by chiefs (a3.7).

(a1) Illustrative Direct Quotations from Commercial Farmers (CF) Interviews.

(a1.1) "Well, people come to our farm and chop down trees to collect the caterpillars (Mopane worms) ...There's one particular variety called the Mutondo [Cordyla Africana] tree which got completely wiped out from my farm…" (CF Interview 8)

(a1.2) "They also came to my farm…and cut these big trees just to get the caterpillars..." (CF Interview 14)

(a1.3) "…this would have been sustainable in the past…, it's obviously something that is a cultural thing…but now it's not sustainable." (CF Interview 6)

(a1.4) "…Mopane worm collectors are very aggressive people, and people have even been killed by them…the affected rural farmers complained to the police and to the chief to no avail…" (CF Interview 7)

(a1.5) "…stopping them was dangerous because these people were very aggressive. They would camp on farmers' lands… as they collected Mopane worms and cut down trees." (CF Interview 9)

(a1.6) "The collectors are well-connected, and they would be bribing the police, they would be bribing the local council people, and …, the police and councils don't have the resources to stop these aggressive Mopane worm collectors." (CF Interview 9)

(a1.7) "Look at this big tree that has just been cut down!... Obviously, there was something in that tree he wanted, either the Mopane worms or the honey…" (CF Interview 10)

(a1.8) "If I take you through this forest, you'll see some beautiful trees that have been cut..." (CF Interview 11)

(a2) Illustrative Direct Quotations from Rural Farmers' Interviews

(a2.1) "Mopane worms are a very good source of income which has helped me supplement income from farming and sometimes even surpassing agriculture income

in yester years. My house has a radio, solar charger and solar lighting… If I work hard, I might even install a solar pump to help with irrigation." (Mkushi Interview 5)

(a2.2) "There are many dangers that I face as I collect caterpillars, like snakes, wasps etc…" (Mkushi Interview 2)

(a2.3) "I collect worms from any forest except where there is a fence…but there are others who dare break fences to collect the worms especially if there is a lot." (Mkushi Interview 3)

(a2.4) "I sell the worms at $25 US (K500)/20ltr container…in a good season you can raise a lot of money…I did not struggle to buy uniforms for my children... necessities, nice phone, radio and the solar lighting…" (Mkushi Interview 2)

(a2.5) "Mopane worm collectors … in groups, carrying axes, pangas and other weapons, so no one dares to stop them…, collecting a large number of worms and making substantial money as they resell them to town people…" (Mkushi Interview 4)

(a2. 6) "Mopane worm numbers have drastically reduced in the past decades because of overharvesting and cutting down of trees... In the past, it was sustainable… but now, there are many people and a very high demand…" (Mkushi Interview 1)

(a3) Illustrative Direct Quotations from Rural Farmers' FGDs

(a3.1) "Mopane worms are a tasty delicacy that has helped many families to survive and also raise some money for buying other household necessities." (Mkushi FGD 2)

(a3.2) "The worms are usually sold wholesale to urban buyers or by the roadside along main roads to passing motorists…" (Mkushi FGD 1)

(a3.3) "The roadside selling is mostly done by women and children, but wholesale selling is done by the men. It's a good alternative source of income to agriculture which is seasonal and once off." (Mkushi FGD 2)

(a3.4) "Commercial Mopane worm collectors are quite aggressive, especially towards people who try to frustrate their collection efforts…" (Mkushi FGD 2)

(a3.5) "…collectors come with machetes and are willing to use them on those opposing them if necessary. Sometimes, the best you can do is to negotiate with them so that they leave you a portion of their collection… a win-win situation…" (Mkushi FGD 1)

(a3.6) "But we don't know what the future holds because there has been overharvesting in recent decades due to increased demand. Mpasa [Julbernadia globiflora], Mutondo [Cordyla Africana] and Miombo [Brachystegia boehmii] trees are mainly the trees that host the caterpillars, and which have been cut down during Mopane worm collection…" (Mkushi FGD 1)

(a3.7) "In the past, caterpillar collection could only start after the chief had given a go ahead… The chiefs also warned against starting any fires during the caterpillar season. These days such issues are not taken seriously..." (Mkushi FGD 2)

(b) Wild Mushroom

The direct quotations illustrate the socio-economic importance of mushroom collection amid environmental and safety challenges. Rural farmers rely on mushrooms as a vital income source, especially during hardships like poor rains and high fertiliser costs (b2.3, b3.4), but they face declining availability due to deforestation and land clearance (b2.1, b3.5). Collectors endure significant risks, such as encounters with wild animals and potential poisoning from misidentified mushroom species (b2.2, b3.1, b3.3). Despite these challenges, mushrooms provide food security and enable investments like solar lighting (b3.6). Commercial farmers recognise their role in sustaining forests and allowing locals to benefit from mushroom harvesting (b1.2, b1.3).

(b1) Illustrative Direct Quotations from CF Interviews

(b1.1) "Apart from local consumption, there is increased demand for mushrooms…the demand is mainly driven by urban area…" (CF Interview 5)

(b1.2) "…many people come through my farm because we try to preserve the forest, which allows mushrooms to thrive. I don't stop them, but I do request that they don't cut down any trees." (CF Interview 9)

(b1.3) "As much as this is my land…I allow the locals to collect mushrooms, which helps them have relish and also to sell and raise some… income." (CF Interview 1)

(b2) Illustrative Direct Quotations from Rural Farmers' Interviews

(b2.1) "It's not easy to find mushrooms (nearby) nowadays because there are very few trees left…also, a lot of land has been cultivated, leading to the loss of forest area..." (Mkushi Interview 3)

(b2.2) "Mushroom collection is not for novices because a lot of people have gotten lost (in the bush) while collecting mushrooms…" (Kapiri Interview 6)

(b2.3) "… there is a good market for mushrooms in urban areas. This helps bring in some income for many of us... I make between £30 US - £35 US (K600 - K700) per week during the peak mushroom season…supplementing income from agriculture… I have a decent phone, a good solar charger, and… good solar lighting." (Mkushi Interview 6)

(b2.4) "It's not always easy to preserve the mushrooms, and some of them end up going bad…" (Chongwe Interview 11)

(b3) Illustrative Direct Quotations from Rural Farmers' FGDs

(b3.1) "Consuming mushrooms is risky because entire families have been poisoned and killed from consuming … poisonous mushrooms… We ensure that we eat and sell only what we know…" (Kapiri FGD 2)

(b3.2) "…Some greedy parents…to earn more money, even take their young school-going children to collect mushrooms..." (Chongwe FGD 3)

(b3.3) “Mushroom collection is a dangerous activity because collectors venture into deep bushes and expose themselves to wild animals, especially snakes…” (Chongwe FGD 1)

(b3.4) “…with fertiliser becoming so expensive… reduction in subsidies…recent poor rains, we would have died of hunger without mushroom…” (Mkushi FGD 1)

(b3.5) “Mushroom thrives well under trees and health forest, sadly the tree numbers have reduced… Land clearance for agricultural purposes is another contributing factor.” (Mkushi FDG 2)

(b3.6) “…we collect enough mushroom and other NTFPs for consumption and selling…many of us use part of income to pay back loans for solar lighting systems which the mobile companies give us...” (Kapiri FGD 2)

(c) Wild Fishing

The direct quotations highlight the critical role of fishing in rural livelihoods, despite environmental degradation and safety challenges. While fish provide both income and nutrition (c2.1, c2.2, c3.1), overfishing and unsustainable practices, such as using small or mosquito nets and fish poison, deplete fish stocks and harm ecosystems (c1.2, c3.2, c3.3). Commercial farmers attempt to regulate fishing on private dams to promote sustainability (c1.1). However, fishing remains perilous, with risks including drowning, crocodile attacks, and snake bites (c3.4). Despite these obstacles, fish sales contribute to household income, supporting basic needs and investments like solar PV lighting (c2.2).

(c1) Illustrative Direct Quotations from CF Interviews

(c1.1) “I allow the locals to fish from my dam, but only if they are using fishing rods and not fishing nets, so that the fish is preserved and protected. (CF Interview 17)

(c1.2) “…sometimes questionable fishing techniques are used especially in public dams and rivers.” (CF Interview 5)

(c2) Illustrative Direct Quotations from Rural Farmers' Interviews

(c2.1) “…I sell the bigger fish to passing motorists... We consume the smaller fish...but there aren’t many fish in this area…”(Kapiri Interview 26)

(c2.2) “…1Kg cost between $6 US to $8 US (K150 to K200… It helps to raise some income for the home when available and even for financing our current solar lighting system…” (Mkushi Interview 3)

(c3) Illustrative Direct Quotations from Rural Farmers' FGDs

(c3.1) “Fish is good relish… but the fish numbers are depleted.” (Kapiri FGD 2)

(c3.2) “People sometimes use illegal fishing methods, like using small nets or even mosquito nets…” (Kapiri FGD 2)

(c3.3) "There are others who use fish poiso (Tephrosia vogelii) … to kill the fish along with any other living organisms in the water..." (Kapiri FGD 2)

(c3.4) "Fishing… comes with many risks. Many people have drowned…, others have been attacked and/or killed by crocodiles, snakes etc or other reptiles while fishing in big streams and rivers." (Mkushi FGD 1)

(d) Bushmeat

The direct quotations reveal the complexities of bushmeat hunting and consumption, highlighting its economic and cultural significance amidst legal and ecological challenges. Bushmeat provides income and sustenance, with profits used for essentials like solar PV lighting (d2.2, d3.1). However, forest loss, restrictions, and the risks of poaching limit supply (d2.1, d2.3, d3.3). Hunters face dangers from wildlife, game rangers, and even supernatural beliefs (d2.4, d3.2, d3.4). While private farms harbour wildlife, access is limited (d2.3, d1.1). Concerns over authenticity and meat quality add to the risks of consumption (d3.5, d3.6). Despite these challenges, bushmeat remains integral to rural livelihoods.

(d1) Illustrative Direct Quotations from CF Interviews

(d1.1) "There are many rabbits on my farm, and some workers hunt them as they use them as relish or sometimes even sell them." (CF Interview 12)

(d1.2) "Rabbits are attracted to car headlights at night, so many are hit and killed…" (CF Interview 4)

(d2) Illustrative Direct Quotations from Rural Farmers' Interviews

(d2.1) "I sell smoked and dried bushmeat…and it's a profitable business despite short supply… due to the many restrictions on bushmeat hunting." (Chongwe Interview 7)

(d2.2) "The demand for bushmeat usually exceeds the supply, but when it's available, I earn enough for essentials like soap, sugar, solar charger, solar torch and solar lighting…" (Chongwe Interview 13)

(d2.3) "Rabbits are difficult to find as the forest cover is decreasing, and most of the rabbits are now found in protected private areas belonging to White commercial farmers…" (Mkushi Interview 2)

(d2.4) "…I used to go hunting with my grandfather…but I opt out, especially when I was pressured to undergo rituals to protect me from wild animals and game rangers…" (Kapiri Interview 26)

(d2.5) "When I find animals that thrive in trees while hunting, and they run up a tree, I cut down the tree." (Kapiri Interview 21)

(d2.6)"…hunting antelopes is illegal in game reserves unless you have a licence. However, when antelopes come near the villages, we kill them for food and sometimes sell..." (Chongwe Interview 14)

(d2.7) "There are several rodents and small animals in this area, but they are not found near the villages…" (Luano Interview 3)

(d3) Illustrative Direct Quotations from Rural Farmers' FGDs

(d3.1) "We love bushmeat… just like urban people… It's supplied by hunters…" (Chongwe FGD 1)

(d3.2) "Many bushmeat hunters also engage in poaching and use magical powers to protect themselves from predators, game rangers…and some have even been associated with human/albino sacrifice." (Kapiri FGD 2)

(d3.3) "Some people have licences and permits to hunt game meat…in some seasons. However, many of them are just armed poachers…" (Chongwe FGD 1)

(d3.4) "Bushmeat hunting is a risky business…because you encounter many dangers… Hence only a few engage in it, and…use charms and magical powers for protection." (Mkushi FGD 2)

(d3.5) "…we are very careful before consuming bushmeat because unscrupulous people sometimes sell dog meat as bushmeat…" (Kapiri FGD 2)

(d3.6) "Though we buy bushmeat from trusted suppliers, we are still cautious and inspect the meat to ensure it is well-preserved and not rotten; otherwise, you can get sick." (Mkushi FGD 1)

(e) Ethnomedicine and Traditional Healing

The direct quotations highlight the coexistence of traditional and modern medicine in rural communities, reflecting both practical reliance and cultural beliefs. Traditional healers are vital due to limited access to clinics and their confidentiality in treating sensitive ailments like STIs (Sexually Transmitted Infections) (e2.1, e3.1). Witch doctors also address spiritual and social issues, earning significant income (e2.4, e3.3). However, scepticism persists, with concerns about their practices, moral implications, and risks, such as discouraging conventional treatment for serious diseases (e3.5, e2.5). While some view traditional remedies as complementary to modern medicine (e3.6), others reject them outright, associating them with superstition and harm (e1.2, e2.5).

(e1) Illustrative Direct Quotations from CF Interviews

(e1.1) "…certain trees, fruits, roots, and other plants have medicinal properties that locals use..." (CF Interview 6)

(e1.2) "There are many superstitions/mystical beliefs in the rural community…, but as a Christian, I encourage them to trust in God…" (CF Interview 15)

(e1.3) "I am aware of the traditional medicines used, especially by people who live far from clinics and town centres. However, I personally rely on conventional medicine." (CF Interview 12)

(e1.4) "Though the large majority of commercial farmers are white, we ensure that we respect the belief systems of the local communities and honour their chiefs..." (CF Interview 5)

(e2) Illustrative Direct Quotations from Rural Farmers' Interviews

(e2.1) "A lot of us combine conventional and traditional medicine. Clinics are few and sometimes very far, so we use traditional healers who are always within reach." (Chongwe interview 3)

(e2.2) "Modern medicine is limited, so you cannot go to the clinic for spiritual problems…for such issues, you go to witch doctors." (Kapiri Interview 19)

(e2.3) "There was a powerful witch doctor in Chongwe called "Mugwegwenu"… who was so good that people used to come from all over, and he made some good money..." (Chongwe Interview 4)

(e2.4) "We have some good witch doctors around who help heal many illnesses, including STIs, and people come from urban areas to seek charms to help in marriage, promotion, business success, fertility..." (Chongwe Interview 4)

(e2.5) "I am a Christian and I don't believe in witch doctors; they are evil and use evil spirits. They bring enmity between neighbours and in families… I believe they are to blame for ritual killings and human sacrifice. They should just be banned." (Kapiri Interview 10)

(e2.6) "I bought this farm at a giveaway price because the previous owner was convicted of practicing witchcraft and banished from the village by the Chief…" (Kapiri Interview 7)

(e3) Illustrative Direct Quotations from Rural Farmers' FGDs

(e3.1) "Traditional healers are more confidential, so people who suffer from embarrassing diseases like STIs…prefer to visit traditional healers to avoid shame… some people recover from serious STIs even within a week…" (Chongwe FGD 3)

(e3.2) "Witch doctors make lots of money. They charge around $2 US (K50) for diagnosis and about $12 US (K300) for treatment and medication. For STIs, though their concoctions work, I believe conventional medicine is better except there is no confidentiality at clinics…" (Chongwe FGD 1)

(e3.3) "For spiritual purging, ghost cleansing, business boosts, etc., the charge is around $120 US (K3,000) depending on the witch doctor. Some make lots of money and some have iron sheet roofs, nice bikes and huge solar panels on top." (Kapiri FGD 2)

(h3.4) "Salt and vinegar are sometimes also used for spiritual cleansing. The charge for salt is about $1 US (K25), while vinegar goes for around $2.50 US (K65)…" (Mkushi FGD 1)

(e3.5) "I use some local remedies to treat illnesses, but I don't trust these witch doctors. They claim to heal any disease, including cancer and HIV... stopping people from taking ARVs…they have led to a lot of deaths." (Mkushi FGD 1)

(e3.6) "The medicines found in hospitals are just purified versions of the God given medicinal plants and roots which freely surround us…" (Mkushi FGD 2)

11.6 Discussion and Interpretations of Findings

11.6.1 Mopane Worms

The discussion of the environmental and social impacts of self-financed solar photovoltaic (PV) systems in rural Zambia, particularly in relation to edible NTFPs like Mopane worms, reveals a complex interaction between income generation, deforestation, and socio-cultural factors. Empirical evidence suggests that the commercialization of Mopane worms, which thrive on trees such as Mutondo [Cordyla Africana], Mpasa [Julbernadia globiflora], and Miombo [Brachystegia boehmii], leads to substantial deforestation, negatively impacting both ecosystems and livelihoods (Mkushi Interview 1, CF 8). Commercial farmers, for instance, express concerns over the widespread felling of large trees to access these caterpillars (CF Interview 8,10,11,14). The rapid and often unauthorised harvesting undermines sustainable land management, resulting in a loss of critical tree species that serve as hosts for the caterpillars, exacerbating deforestation pressures (CF Interview 8).

This aligns with the findings of Chidumayo and Mbata (2002), who highlight that overharvesting of host trees is a critical issue in maintaining the sustainability of caterpillar harvesting. While younger miombo woodlands exhibit higher regeneration rates after disturbances such as selective cutting, older woodlands face higher mortality rates and poorer regeneration potential, thus diminishing their long-term capacity to support edible caterpillars. The destruction of key tree host species, such as Mutondo and Mpasa, further threatens this dynamic, compromising both biodiversity and the long-term availability of NFTPs.

The financial benefits derived from Mopane worm collection cannot be overlooked, as rural households often report significant income (with some earning as much as $25 US per 20 litre container of caterpillars) from selling the worms, which even at times surpasses agricultural returns during peak seasons (Mkushi Interview 2). This supports earlier studies that have documented the significant economic contribution of edible caterpillars to household income and food security across SSA (Hlongwane et al., 2021b; Makhado et al., 2014). However, this income generation comes at a high environmental cost, with evidence of overharvesting, reduced worm populations, and weakened forest ecosystems (Mkushi FGD 1).

Socially, the collection of Mopane worms is marked by growing tensions. Commercial collectors, often migrating across territories, pose significant challenges to both local farmers and traditional authorities (Mkushi FGD 2). In some instances, their aggressive behaviour has led to fatalities (CF Interview 7) and violence, illustrating the socio-economic desperation driving this trade (CF Interview 9,7,14). These findings resonate with broader regional challenges, where weak governance structures and limited regulatory enforcement have led to unsustainable practices in communal areas (Sekonya et al., 2020; Togarepi et al., 2020).

The introduction of solar PV systems, cited by local farmers as an important tool in improving household well being, has helped offset some environmental pressures on local forests that would be affected by mopani worm harvest; PV reduces dependency on firewood while enhancing clean energy access (Mkushi Interview 5). Nonetheless, without stronger regulations and sustainable harvesting practices for Mopane worms, these efforts alone are unlikely to mitigate the broader environmental degradation resulting from the overexploitation of NTFPs. Sustainable management and community-based governance, as suggested in the literature (Chidumayo and Mbata, 2002), remain crucial for ensuring the continued viability of both solar energy initiatives and Mopane worm harvesting as complementary livelihood strategies in rural Zambia.

11.6.2 Wild Mushroom

The integration of self-financed solar photovoltaic (PV) systems into rural Zambia has had notable environmental and social impacts, particularly regarding the sustainable harvesting of edible NTFPs such as wild mushrooms. Empirical evidence from commercial and rural farmers in Zambia indicates that wild mushrooms play a crucial role in both food security and income generation. During the peak season, farmers reported weekly earnings ranging from £30 US to £35 US (K600-K700), contributing significantly to household income (Mkushi Interview 6). This mirrors findings from previous studies, where mushroom commercialization in SSA demonstrated a similar income potential, with Amanita loosii mushrooms fetching between US$0.10 US and US$1 US per litre in Zimbabwe (Mlambo and Maphosa, 2017). The income generated from wild mushroom sales helps rural households manage financial obligations, such as repayments for solar PV lighting systems (Mkushi Interview 6, Kapiri FGD 2).

The growing demand for mushrooms, particularly in urban areas where they are valued for their health benefits, has encouraged increased foraging (CF Interview 5). However, the mushroom sector faces numerous challenges, including the depletion of forest cover, which is critical for mushroom proliferation. As noted by farmers, the loss of trees and deforestation, often driven by agricultural expansion, has adversely affected mushroom availability (Mkushi FGD 2). This is consistent with research findings from Steel et al. (2022) and Sileshi et al. (2023), both of which emphasise the detrimental impact of deforestation on the sustainability of wild mushroom resources in SSA.

Social issues also emerge from mushroom commercialization. The need for income has led some households to prioritise foraging over education, with children missing school to help collect mushrooms (Chongwe FGD 3). Furthermore, the dangers of venturing into deep forests and use of inexperienced gatherers expose collectors to risks from wild animals and consumers to poisonous mushrooms (Chongwe FGD 1, Kapiri FDG 2). Therefore, while wild mushrooms contribute to income generation, these activities present ecological and social challenges that require careful management to ensure the long-term viability of NTFP-based livelihoods in rural Zambia.

11.6.3 Wild Fishing

Our empirical evidence reveals that apart from fish being consumed, income generated from fishing (approximately $6 US to $8 US per kilogram of fish) has enabled rural households to finance the acquisition of solar PV systems, highlighting the integral role of fishing in rural income generation (Mkushi Interview 3, Kapiri Interview 26, Kapiri FGD 2). This reflects broader findings across SSA, where fishing serves as both a critical income source and food security measure (Gondwe et al., 2023; Temesgen et al., 2019). The income from fish sales contributes not only to daily sustenance but also to broader investments in sustainable energy, showing a direct link between fishing income and improved household infrastructure, such as solar PV systems.

However, despite the socio-economic benefits derived from fishing, there are significant ecological and economic challenges associated with wild fishing in Zambia. Evidence from the focus groups and interviews suggests that overfishing, depletion of fish stocks, and the use of destructive fishing methods, including fish poison (Tephrosia vogelii), threaten the long-term sustainability of fisheries (Kapiri FGD 2; CF Interview 5). This mirrors broader concerns across the region, where overfishing and environmental degradation severely impact aquatic ecosystems, undermining the viability of fishing as a reliable income source (Temesgen et al., 2019; Tweddle et al., 2015). Additionally, unsustainable practices, such as the use of small nets and fishing in ecologically sensitive areas, compound the ecological risks, leading to the gradual depletion of natural resources crucial for rural livelihoods (Kapiri FGD 2.).

The low productivity of small scale fisheries, exacerbated by seasonal fishing bans and inadequate infrastructure, limits the income potential for rural households (Kapembwa et al., 2021). Furthermore, safety risks, such as crocodile or snake attacks and drowning incidents, present additional barriers to the sustainability of fishing as an income source (Mkushi FGD 1).

11.6.4 Bushmeat

Bushmeat serves as an essential yet ecologically and socially complex source of income in rural SSA, including Zambia. Findings indicate that rural households rely on bushmeat trade to supplement livelihoods in contexts of limited economic opportunities (Chongwe Interviews 7, 13). This aligns with studies by Kouassi et al., 2023 and Lindsey et al., 2011, which highlight poverty and unemployment as drivers of rural dependence on bushmeat. Increasing urban demand has shifted hunting from subsistence to commercial trade, as similarly observed by Brown & Marks (2008). The economic significance of bushmeat in Zambia is underscored by its role in addressing financial and food security needs. Farmers engage in bushmeat trade despite legal restrictions, using earnings to purchase essential goods (Chongwe Interview 13, CF Interview 12). White & Belant (2015) emphasise bushmeat's critical role in alleviating food insecurity, estimating an annual yield of 129,000 kg valued at over $600,000 US in Zambia. Particularly during periods of food scarcity, hunting in game management areas helps rural households mitigate shortages.

While Zambia's Wildlife Act (2015) permits regulated hunting, illegal bushmeat trade remains pervasive due to urban demand, particularly in Lusaka, where annual trade volumes are estimated at 1,140 tonnes (Davies, 2017). The gap between demand and legal supply has fuelled illegal hunting, with around 6,000 people involved in such activities in the Greater Kafue Ecosystem alone (Davies, 2017). This dynamic exacerbates habitat conversion for agriculture to meet growing food needs, further intensifying environmental pressures (Alexander et al., 2015). The ecological costs of the bushmeat trade are profound. Overhunting, especially in areas with limited wildlife protection, threatens biodiversity and disrupts population dynamics of species like antelopes and rabbits (Mkushi Interview 2, Luano Interview 3). These findings align with broader concerns about unregulated hunting's impact on ecosystems, as noted by Che et al. (2017) and Foya et al. (2023). Furthermore, the bushmeat trade poses zoonotic disease risks by facilitating pathogen transfer from wildlife to humans, a critical issue identified by (Kurpiers et al., 2015).

Social and cultural factors further complicate bushmeat reliance. Traditional rituals often accompany hunting, reflecting a fusion of spiritual beliefs and survival strategies. Hunters in Kapiri, for instance, rely on mystical practices for protection, paralleling practices documented in Nigeria by Paul Mmahi & Usman (2020). These rituals serve as coping mechanisms to mitigate risks, including confrontations with game rangers and dangerous wildlife (Mkushi FGD 2). The bushmeat trade in Zambia presents a persistent and challenging balance between economic necessity and environmental sustainability. While it provides critical income for rural households, its environmental and social impacts are undeniably severe. Ripple et al. (2016) and Wicander & Coad (2018) advocate for alternative livelihoods as a means to reduce illegal hunting and associated ecological degradation. This approach fits well with findings from the Wildlife Economy Hub for Africa, which suggests that well-managed, legal hunting can alleviate pressures on wildlife populations (Vigne, 2022). However, as urban demand for bushmeat continues to rise, without viable economic alternatives, illegal hunting and its environmental consequences are likely to persist.

11.6.5 Ethnomedicine and Traditional Doctors

This study highlights the critical role of income from traditional healing practices in financing solar PV systems in rural Zambia. Traditional healers and Ethnomedicine practitioners (witch doctors), who offer medicinal and spiritual services, are pivotal economic actors in these communities. Income from such practices constitutes up to 58% of household earnings in remote areas with limited access to modern healthcare (Timmermann and Smith-Hall, 2019). Fees for services vary significantly, ranging from $2 US (K50) for diagnoses to $120 US (K3,000) for rituals like spiritual purging or business-boosting ceremonies (Chongwe FGD 1; Kapiri FGD 2). Many households rely on a combination of traditional and modern medicine due to affordability and accessibility challenges, with 70% of Zambia's population using medicinal plants for healthcare (Boukandou Mounanga et al., 2015; Nyirenda and Chipuwa, 2024).

Traditional medicine not only provides essential healthcare but also generates significant household income. For instance, healers treat STIs using herbal remedies derived from plants like Strychnos cocculoides (Chongwe FGD). This income enhances economic resilience and supports solar PV adoption (Kapiri FGD 2). However, overreliance on ethnomedicine poses sustainability challenges. Demand for key ingredients like lemon and papaya roots is driving overharvesting, threatening the long-term availability of these resources (Kapiri Interview 19; Mkushi FGD 1). Similar concerns apply to Cassia abbreviata (Umunsokansoka), which effectively treats malaria and STIs but faces risks from unsustainable harvesting practices (Sidney et al., 2024). The lack of regulatory oversight on medicinal plant harvesting and commercialization not only threatens environmental sustainability but potentially also undermines the availability of vital healthcare resources (Boukandou Mounanga et al., 2015; Sher et al., 2014). Cultural factors also influence the preference for traditional medicine. Stigma surrounding STIs often discourages individuals from seeking treatment in modern clinics, as traditional healers ensure confidentiality and social acceptance (Chongwe FGD 3). This is corroborated by findings in Monze, where more than 80% of respondents identified stigma as a primary barrier to STI treatment (Simbeye et al., 2024). Traditional medicine thus serves as a culturally sensitive alternative, addressing both medical and social needs. This aligns with (Gausset's (2001) argument that Western (Modern) healthcare programmes in SSA often fail to accommodate culturally acceptable practices, alienating local populations and reducing programme effectiveness. By offering a socially acceptable means of treatment, ethnomedicine not only addresses healthcare gaps but also fosters trust within local communities (Chinsembu et al., 2019; Gausset, 2001).

However, Ethnomedicine practitioners, while economically significant for some households, introduce substantial social challenges. Ethnomedicine practitioners in Chongwe and Kapiri provide various treatments and rituals, reflecting the strong belief in spiritual services, including juju rituals, even among individuals adhering to orthodox religions (Aborisade and Adedayo, 2021). Yet, these practices frequently exacerbate social tensions. Witchcraft accusations, social exclusion, and ritual killings, particularly targeting vulnerable groups like individuals with albinism, are some of the adverse consequences documented (Kapiri Interview 10).

The destabilizing effects of witchcraft beliefs are well-established in both the study's findings and broader literature. Such beliefs undermine social cohesion, hinder economic development, and foster mistrust within communities (Gershman, 2016). In Zambia, ritual killings linked to witchcraft practices have heightened fear and social instability, eroding community trust (Aquaron et al., 2009; Mwiba, 2018). These harms emphasise the need for robust legal and social frameworks to regulate witchcraft practices and mitigate their negative impacts on community cohesion (Sanou, 2020). Traditional healing plays a dual role in rural Zambia by addressing healthcare needs and generating critical income, which can support investments in solar PV systems. However, the overexploitation of medicinal plants and the social challenges associated with witchcraft practices necessitate stronger regulation and sustainable management. Balancing economic benefits with environmental sustainability and community well-being is essential for ensuring the long-term viability of these practices.

11.7 Recommendations for Policy and Practice

To advance the adoption of self-financed solar photovoltaic (PV) systems in rural Zambia while promoting the sustainable management of NTFPs such as Mopane worms, mushrooms, bushmeat, fishing, and ethnomedicine, policymakers and practitioners must adopt comprehensive and pragmatic strategies. These recommendations address financing models, stakeholder collaboration, integration of income generation, barriers to adoption, and regulatory frameworks.

11.7.1 Improving Financing Models

Adaptive financing mechanisms aligned with rural income patterns are essential. The Ministry of Energy and the Rural Electrification Authority (REA) should implement flexible repayment models tied to seasonal incomes from NTFPs, such as Mopane worms and fish. Income-linked repayment schemes will enable rural households to invest in solar PV systems without jeopardizing economic stability, ensuring long-term adoption and operational sustainability. Income from NTFPs serves as an effective complementary mechanism to other financing models, particularly for rural, forest-dependent communities. Integrating NTFPs with PAYG systems or microfinance loans can enhance energy access while supporting forest conservation and rural development. Adapting financing approaches to specific regional contexts is critical to achieving optimal community benefits and ensuring long-term sustainability.

11.7.2 Promoting Multi-Stakeholder Collaboration

Effective solar PV implementation requires cohesive action among stakeholders. Ministries overseeing energy, agriculture, and health must collaborate with local councils, traditional leaders, and global development organizations to create inclusive policies. Incorporating local priorities ensures tailored energy solutions while encouraging sustainable NTFP use. Conservation-focused organizations, such as the Zambia Wildlife Authority (ZAWA), are crucial partners in aligning energy initiatives with resource preservation, safeguarding mushrooms and bushmeat ecosystems.

11.7.3 Integrating NTFPs with Renewable Energy Initiatives

Income generation from NTFPs should be strategically linked to solar PV adoption. Promoting sustainable harvesting and community-based processing facilities for products like mushrooms, fish, and medicinal plants can enhance household revenues while reducing environmental impacts. Initiatives such as eco-tourism centred on NTFPs offer alternative income streams, with the ability to incentivise conservation while at the same time fostering renewable energy investments.

11.7.4 Addressing Barriers to Solar PV Adoption

Solar PV adoption faces obstacles such as financial constraints, low awareness, and technical challenges. Public education campaigns should, we argue, highlight solar PV benefits alongside sustainable NTFP harvesting practices. Microfinance institutions and NGOs must provide targeted loans and technical support to enhance accessibility and system maintenance. Capacity-building initiatives are critical to equipping communities with knowledge about solar PV usage and sustainable resource management, particularly for bushmeat and fish.

11.7.5 Strengthening Regulatory Frameworks

Robust regulation is vital to sustaining solar PV systems and conserving natural resources. The Ministry of Lands and Natural Resources should enforce sustainable practices for Mopane worms, mushrooms, and bushmeat harvesting. Community-led governance systems can ensure local accountability, while conflict resolution frameworks address disputes over resource access. Social protection policies should offer alternative livelihoods to ease transitions from unsustainable practices, promoting energy equity and ecological preservation.

11.8 Conclusion Section

This study provides a detailed exploration of the environmental and social effects of self-financed solar photovoltaic (PV) systems in rural Sub-Saharan Africa, focusing on Zambia’s edible NTFPs such as Mopane worms, mushrooms, fishing, bushmeat, and ethnomedicine. By examining the interplay between solar PV adoption and rural livelihoods, it highlights the dual potential of these resources as critical income sources and ecological assets. The findings underscore the importance of sustainable practices, integrated policy interventions, and community-led initiatives to balance energy access with environmental conservation and socio-economic development.

11.8.1 Key Findings

The study reveals that income derived from Mopane worms, mushrooms, fish, bushmeat, and medicinal plants plays a pivotal role in financing solar PV systems in rural Zambia. These NTFPs often serve as primary or supplementary income sources, sometimes exceeding the returns from agriculture. This financial capacity facilitates solar PV adoption, enhancing household energy access and reducing dependence on unsustainable biomass energy, such as firewood. By doing so, solar PV systems contribute to mitigating deforestation and associated carbon emissions. However, the commercialization of the NTFPs also raises significant environmental concerns, particularly overharvesting, habitat destruction, and biodiversity loss, which threaten long-term sustainability.

11.8.2 Environmental Impacts

While solar PV systems offer environmental benefits by reducing reliance on firewood and mitigating carbon emissions, the income activities enabling their financing often pose ecological risks. The overharvesting of Mopane worms and wild mushrooms depletes natural stocks, undermining ecosystem stability and species diversity. Similarly, unsustainable fishing practices erode aquatic biodiversity, while bushmeat extraction jeopardises wildlife populations. These environmental challenges necessitate effective resource management strategies that prioritise sustainable harvesting and ecological preservation. Without such measures, the dual pressures of resource depletion and increasing energy needs could undermine both environmental and energy sustainability objectives.

11.8.3 Social Impacts

Socially, the integration of solar PV systems into rural communities has transformative potential, improving energy access and household well-being. The income from NTFPs empowers households financially, enhancing their ability to invest in modern energy technologies. However, commercialization of resources like bushmeat and fish can exacerbate social tensions, particularly, where competition for finite resources fuels conflicts between traditional harvesters and commercial operators. Such dynamics risk deepening socio-economic disparities and destabilizing community cohesion. Solar PV systems, while beneficial, cannot independently address the challenges; robust regulatory frameworks and community driven governance structures are essential to promote equitable access and collective resilience.

11.8.4 Implications for Access and Sustainability

This research underscores the interconnected nature of energy access, poverty alleviation, and environmental sustainability in rural Zambia. Integrating solar PV systems with sustainable NTFP management presents a unique opportunity to enhance rural livelihoods while safeguarding natural ecosystems. For instance, promoting sustainable harvesting practices for Mopane worms and mushrooms, alongside eco-friendly fishing techniques, could balance income generation with conservation efforts. Educational campaigns and capacity building initiatives are critical for equipping communities with the knowledge to manage resources responsibly. Furthermore, investing in alternative livelihoods, such as value-added processing of NTFPs or eco-tourism linked to ethnomedicine, can diversify income sources and reduce overdependence on vulnerable resources.

11.8.5 Contribution to Knowledge

This study contributes important insights and depth of understanding to the discourse on rural development by elucidating the complex interplay between income generation, energy access, and environmental conservation. It highlights the dual role of NTFPs as economic enablers of solar PV adoption and as ecological assets requiring protection. By advocating for sustainable harvesting and integrated energy policies, the findings emphasise the importance of aligning renewable energy initiatives with natural resource management. This dual focus approach is crucial for achieving long-term rural development goals, balancing socio-economic resilience with environmental integrity. Income from NTFPs serves as an effective complementary mechanism to other financing models, particularly for rural, forest dependent communities. Integrating NTFPs with PAYG systems or microfinance loans can enhance energy access while supporting forest conservation and rural development. Adapting financing approaches to specific regional contexts is critical to achieving optimal community benefits and ensuring long-term sustainability.

We have introduced the novel Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM), which integrates three key theoretical frameworks to provide a comprehensive understanding of the factors influencing renewable energy adoption in rural areas. This holistic approach accounts for the interplay between individual beliefs, social influences, and community dynamics in shaping adoption behaviours. By offering valuable insights into the complexities of solar PV adoption, RUDSHAM serves as a crucial tool for policymakers, researchers, and practitioners seeking to develop effective strategies for sustainable energy transitions in rural communities.

11.8.6 Future Directions and Recommendations

While this study advances understanding of the relationship between solar PV systems and NTFPs, its limitations suggest avenues for future research. A longitudinal approach would provide deeper insights into the long-term impacts of solar PV adoption on rural households and ecosystems. Expanding the geographical scope to include other Sub-Saharan African countries could uncover regional variations and commonalities in adoption dynamics. Quantitative methodologies, such as large-scale surveys, would enhance the generalizability of findings, while a broader examination of economic activities beyond NTFPs could provide a more holistic understanding of rural energy transitions.

In conclusion, solar PV systems, when combined with the sustainable management of NTFPs, provide a viable pathway to alleviating energy poverty and promoting environmental conservation in rural Zambia. Using the RUDSHAM framework, we have presented detailed findings and empirical evidence that demonstrate tangible improvements in local communities through solar PV adoption. For example, the provision of lighting has directly benefited schoolchildren by enabling nighttime study, reduced the risks posed by snakes in the dark, extended shop operating hours, and minimised health hazards associated with candle smoke inhalation and fire risks.

Additionally, households with larger solar PV systems have been able to irrigate gardens using solar-powered water pumps, operate salons, and raise chickens, thereby increasing their income. These findings highlight both economic and quality-of-life improvements. Achieving this balance requires collaborative efforts among policymakers, communities, and development practitioners to design policies and interventions that integrate energy access with sustainable livelihoods. By addressing the confluence of challenges embracing resource depletion, social inequity, and energy poverty, rural communities will potentially be able – effectively and efficiently – to transition toward a more sustainable and equitable future. This research thus serves as both a knowledge contribution and a call to action for advancing sustainable rural development in Zambia.

Chapter 12: Policy Recommendations for Managing Solar PV Adoption

This section synthesises policy recommendations derived from the empirical findings of the thesis, aligning them with the stated research objectives. The recommendations are organised under cross cutting themes, reflecting the multifaceted nature of solar photovoltaic (PV) adoption in rural Zambia. Each recommendation incorporates relevant governmental ministries, agencies, and organisations.

12.1 Integrated Energy and Environmental Governance

These sections recommendations draw primarily on the findings of Article 1, Energy transitions in Sub-Saharan Africa: Policy recommendations for charcoal trade, solar PV adoption, and sustainability in rural Zambia, and Article 2, The African Clean Energy - Deforestation Paradox: Examining the sustainability trade-offs of rural solar energy expansion in Zambia. These articles demonstrate that solar PV adoption in rural Zambia is frequently financed through charcoal production and other environmentally degrading activities, thereby creating a Clean Energy - Deforestation Paradox. The evidence shows that without integrated governance linking energy access targets to forest conservation and sustainable biomass management, solar expansion risks reinforcing deforestation and environmental degradation rather than alleviating it.

12.1.1 Align Energy with Forest Conservation

To address the environmental implications of solar PV expansion, particularly concerning deforestation and biomass fuel reliance, the Ministry of Energy and the Ministry of Green Economy and Environment (MoGEE) should collaboratively develop a unified policy framework. This framework should align renewable energy targets with forest conservation goals, ensuring that solar energy initiatives do not inadvertently encourage unsustainable practices such as charcoal production or overharvesting of non-timber forest products (NTFPs). The Ministry of Finance, in partnership with the Rural Electrification Authority (REA), should introduce forest-sensitive solar subsidies and zero-interest loan schemes for rural households. International partners, for example, the United Nations Development Programme (UNDP) and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), can provide support to ensure these financial mechanisms are inclusive and environmentally considerate.

12.1.2 Inter-Ministerial Collaboration for Implementation

Effective implementation of integrated energy and environmental policies necessitates robust inter-ministerial collaboration. The Ministry of Energy, MoGEE, and the Ministry of Agriculture should establish joint task forces to oversee the synchronisation of energy projects with environmental conservation efforts. These task forces should facilitate data sharing, joint planning, and coordinated monitoring to ensure that solar

PV initiatives contribute positively to both energy access and environmental sustainability.

12.2 Community-Driven Adoption and Social Inclusion

The recommendations under this section are grounded in the empirical insights from Article 3, Community Led Solar Energy Technology Adoption in Rural Zambia: The Role of Observational Learning and Neighbour Influence, supported by the livelihood findings in Articles 6 and 7. Article 3 shows that solar PV adoption and sustained use are strongly shaped by community level processes, including social learning, neighbour influence, and informal leadership, rather than by top-down interventions alone. Articles 6 and 7 further illustrate how uneven participation and unequal access can reproduce social exclusion in forest adjacent communities. Together, these findings justify policies that strengthen local governance structures, promote peer led strategies, and explicitly foreground gender equity and social inclusion in energy planning.

12.2.1 Empowering Local Governance Structures

Recognising the pivotal role of community ownership in the success of solar PV projects, the Ministry of Local Government and Rural Development should enhance the capacity of Ward Development Committees (WDCs). Investments in training and logistical support, in line with the Local Government Act No. 2 of 2019, will enable WDCs to effectively co-manage decentralised solar infrastructure, encompassing planning, implementation, and maintenance.

12.2.2 Peer-Led Strategies Using Social Capital

The Ministry of Energy and REA should support peer led adoption strategies by identifying and training "solar champions" within communities. These individuals can demonstrate the benefits of solar PV systems, fostering observational learning and influencing community uptake. Such strategies are particularly effective in resource constrained rural contexts, where trust and social networks play a significant role in technology adoption.

12.2.3 Promoting Gender Equity in Energy Access

To ensure equitable energy transitions, the Ministry of Gender and Child Development, in collaboration with UN Women Zambia and the African Women in Energy and Environment Foundation (AWEEF), should implement gender-focused financial literacy training and vocational programmes tailored to women entrepreneurs in the clean energy sector. These initiatives should be integrated with broader policy support from the Ministry of Small and Medium Enterprises Development (MSMED) to promote women-led solar enterprises and cooperative energy ventures, thereby preventing economic marginalisation of women in forest-dependent communities.

12.3 Sustainable Livelihoods and Forest Management

This section is informed by evidence from Articles 1, 2, 6, and 7. Article 1 reveals the dependence of many rural households on charcoal and other forest based incomes, while Article 2 highlights the broader sustainability trade-offs when such activities are used to finance solar adoption. Articles 6 and 7 provide detailed empirical analysis of how solar PV interacts with livelihoods based on wild foods, honey, fruits, traditional beer, mopane worms, mushrooms, fishing, bushmeat, and ethnomedicine. These studies collectively show that livelihoods and forest ecosystems are tightly interlinked and that solar adoption can either support or undermine these relationships. This evidence underpins the recommendation to link solar policies with diversified livelihood support, sustainable forest product certification, and community-based conservation and reforestation initiatives.

12.3.1 Link Solar with Livelihood Sustainability

To reduce reliance on charcoal and promote sustainable energy financing, the Ministry of Community Development and Social Services, alongside partners such as the World Food Programme (WFP) and the SNV Netherlands Development Organisation (SNV), should scale up support for agroforestry, beekeeping, mushroom farming, and eco-tourism. These livelihood activities can provide alternative income sources, enabling rural households to invest in solar PV systems.

12.3.2 Certify Sustainable Forest Product Practices

The Ministry of Commerce, Trade and Industry, in coordination with the Zambia Forestry and Forest Industries Corporation (ZAFFICO) and the International Union for Conservation of Nature (IUCN), should develop national certification schemes for sustainably produced charcoal and other forest products. Such schemes can enhance market access and incomes for compliant producers while mitigating environmental degradation.

12.3.3 Promote Reforestation and Conservation Farming

The Ministry of Agriculture and the Department of National Parks and Wildlife should collaborate to promote conservation agriculture practices and reforestation efforts. Community-led initiatives, supported by organisations like North Swaka Trust (NST) and the World Wildlife Fund for Nature Zambia (WWF Zambia), can facilitate the sustainable management of wild fruit species and other NTFPs, linking these efforts to solar PV adoption incentives for forest-adjacent households.

12.4 Technology Regulation and Waste Management

The policy measures proposed in section 12.4 are directly supported by Article 4, The solar e-waste challenge: A Zambian case study of informal disposal, counterfeit technologies and low literacy. Article 4 documents the rapid emergence of informal and often hazardous e-waste handling practices in rural Zambia, including burial, burning, and unsafe storage of damaged solar components, alongside widespread circulation of counterfeit and substandard technologies. It also highlights low levels of consumer literacy and weak regulatory oversight in both formal and informal markets. These findings provide clear empirical justification for strengthening regulation against counterfeit products, improving aftersales support and repair services, and developing a dedicated national framework for solar specific waste management.

12.4.1 Strengthen Regulation Against Solar Counterfeits

The influx of counterfeit solar technologies necessitates stronger market governance. The Zambia Bureau of Standards (ZABS), Zambia Revenue Authority (ZRA), and Zambia Compulsory Standards Agency (ZCSA) should collaborate on the quality control of solar imports. Simultaneously, the Ministry of Commerce, Trade and Industry must regulate informal markets to protect consumers.

12.4.2 Provide Aftersales Support and Training

The Energy Regulation Board (ERB) should enforce warranty compliance and user-centred design principles among solar PV providers. This includes establishing decentralised repair hubs, supported by non-governmental organisations such as Practical Action Zambia and the Zambia Chamber of Commerce and Industry, to professionalise rural solar technicians and enhance system reliability.

12.4.3 National Framework for Solar Waste

To address the growing challenge of solar e-waste, MoGEE and the Zambia Environmental Management Agency (ZEMA) must urgently develop a national solar-specific waste management framework. This framework should encompass rural collection centres and producer take-back schemes, with support from organisations like SolarAid, GIZ Zambia, and the International Renewable Energy Agency (IRENA).

12.5 Financial Models and Enterprise Development

The recommendations in section 12.5 are informed by evidence from Articles 1, 5, 6, and 7. Article 1 points to structural affordability barriers and the tendency of households to rely on environmentally harmful income sources to finance solar systems. Article 5, Exploring the nexus of solar adoption, sustainability, and rural community development through the role of White commercial farmers: The case of Mkushi, Zambia, shows how locally embedded actors and hybrid financing arrangements can expand access to decentralised solar infrastructure. Articles 6 and 7 further reveal how solar PV investments are closely tied to seasonal and often precarious livelihood incomes. Together, these findings support the need for context sensitive financial tools, targeted support to informal vendors and cooperatives, and the expansion of rural solar enterprises and cooperatives that can offer more inclusive and sustainable pathways to ownership.

12.5.1 Create Context-Sensitive Financial Tools

To overcome cost barriers to solar PV adoption, the Ministry of Finance and REA should promote context-sensitive financial models, such as pay-as-you-go (PAYG) schemes and revolving community loans. Private companies like Fenix International have demonstrated the effectiveness of such models, which should now be scaled nationally.

12.5.2 Supporting Informal Vendors and Cooperatives

The United Nations Capital Development Fund (UNCDF) and local microfinance institutions should offer targeted support to informal vendors and cooperatives, facilitating their transition towards formal, sustainable solar business practices. This support can stimulate local entrepreneurship and reinforce energy access.

12.5.3 Expanding Rural Solar Cooperatives

The Ministry of Small and Medium Enterprise Development and the Zambia Development Agency should expand rural solar cooperatives offering input credit, solar leasing, and revolving loans. Partnerships with the Zambia Social Investment Fund (ZAMSIF) and microfinance organisations will enhance inclusivity and affordability.

12.6 Education, Awareness, and Behavioural Change

This section is grounded primarily in the behavioural and informational insights from Articles 3 and 4, supplemented by broader contextual findings from Articles 1 and 2. Article 3 shows that peer learning, social norms, and local narratives significantly influence how households perceive solar technologies and decide whether to adopt and maintain them. Article 4 demonstrates that low literacy, limited understanding of product quality, and poor awareness of e-waste risks contribute to unsafe disposal practices and vulnerability to counterfeit technologies. Articles 1 and 2 also indicate that many households are not fully aware of the long-term environmental implications of financing solar through charcoal and other unsustainable practices. These findings underpin the recommendation to invest in vernacular based energy literacy, school based sustainability education, and inclusive communication strategies that engage multiple community actors.

12.6.1 Integrate Sustainability into School Curricula

Long-term transformation requires embedding sustainability education into national curricula. The Ministry of Education should incorporate topics on renewable energy, environmental conservation, and sustainable practices from early childhood education onwards. Community campaigns, funded through donor partnerships, can complement formal education by promoting forest stewardship and sustainable energy habits.

12.6.2 Use Vernacular-Based Energy Literacy Programs

The Ministry of General Education (MoGE) and REA should co-develop vernacular-based, audio-visual learning tools addressing solar usage, counterfeit risks, and e-waste disposal. Outreach via community radio, faith-based organisations, and traditional leadership will enhance reach and impact.

12.6.3 Promote Inclusive Research and Communication

The Ministry of Information and Media, in collaboration with the Zambia Institute for Policy Analysis and Research (ZIPAR), should lead inclusive communication campaigns recognising the role of diverse actors, including White commercial farmers, in energy transitions. A research ethics framework promoting participatory, community-based methodologies should be developed to ensure ethical engagement with rural communities.

12.7 Infrastructure Development and Institutional Capacity

The recommendations in section 12.7 are largely supported by Article 5, which analyses the role of White commercial farmers in shaping solar adoption, local infrastructure, and rural development in Mkushi. Article 5 shows that these non-traditional actors often possess capital, technical capacity, and existing infrastructure that can be leveraged to extend electrification and shared services to surrounding communities, but that their contributions remain informal and weakly integrated into national energy planning. Complementary insights from Articles 1, 3, and 7 indicate that institutional capacity at local level is uneven and that community institutions frequently lack formal mechanisms to engage with such actors. On this basis, the recommendations advocate formal recognition of White commercial farmers within decentralised energy policy frameworks and the creation of multi stakeholder platforms that strengthen coordination between farmers, smallholders, traditional leaders, and public agencies.

12.7.1 Formalising the Role of WCFs in Electrification Policy

The Ministry of Energy and REA should formally include White commercial farmers in decentralised solar energy frameworks. Public-private partnerships could be developed to enable shared solar mini-grids, leveraging White commercial farmers' land and infrastructure to develop mini-grids that extend access to nearby off-grid communities.

12.7.2 Platforms for Multi-Stakeholder Development

The Ministry of Local Government and Rural Development should coordinate district-level forums integrating White commercial farmers, smallholders, traditional leaders, and civil society.

Chapter 13: Conclusions and Recommendations

13.1 Critical Findings and Theoretical Contributions

This thesis provides an integrated, empirically grounded exploration of decentralised solar PV adoption in rural Zambia, critically informed by the Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM). Spanning seven interlinked studies, the research offers new insights into the environmental/social trade-offs, social learning pathways, e-waste dynamics, non-traditional actors, and the livelihood implications of rural solar transitions.

The discussion is organised around five cross-cutting themes that align with the research objectives and collectively advance theory and practice in the field of rural energy transitions.

13.1.1 Energy and Deforestation Paradox Explained

One of the most compelling findings of this thesis is the Clean Energy - Deforestation Paradox, whereby the very processes that enable households to finance the adoption of solar PV, such as charcoal production, bark stripping, or NTFP harvesting, exacerbate environmental degradation. Contrary to dominant narratives that frame solar PV as inherently sustainable, this research reveals that income for clean energy investment is often sourced from unsustainable ecological practices, thus offsetting many of the environmental benefits.

Articles 1, 2, 6, and 7 collectively demonstrate that charcoal production and the harvesting of wild honey, mopane worms, and mushrooms, though vital to household income, contribute to forest loss and biodiversity threats. The introduction of the Forest to Solar Economic Trade-Off Ratio (Article 1) quantifies this dynamic, showing that roughly 20 trees must be felled to match the cost of a basic solar PV lighting system. These finding challenges policy assumptions and calls for a reconceptualisation of energy transitions, not as linear advancements but as embedded trade-offs within marginalised rural economies.

Theoretical implications include a rethinking of sustainability discourses to include not only energy outcomes but the processes and means by which energy is accessed. Practically, this thesis argues for integrated policy frameworks that connect forestry, conservation, and rural energy policy. Mitigating environmental degradation will require simultaneous investment in alternative livelihood programmes, NTFP value chains, and environmental education.

13.1.2 Community Dynamics in Solar Adoption

Social learning emerged as a central theme in understanding how rural Zambians adopt and engage with solar PV systems. Article 3 shows that observational learning, peer influence, and local leadership are far more significant than formal awareness campaigns or top-down distribution models. RUDSHAM’s incorporation of Social

Learning Theory proved critical in mapping how technology flows through trusted networks and how positive demonstration effects shape individual decision-making.

Importantly, community-led approaches outperform externally driven interventions in long-term sustainability. Reliance on donor support or government subsidies, without meaningful community engagement, has been shown to breed dependency and undermine maintenance and ownership. Instead, projects where communities were involved in planning, financing, and managing technology adoption exhibited greater resilience, accountability, and operational longevity.

The practical implication is the need to reorient energy policy and NGO programming toward facilitating local governance of energy resources, with capacity building for solar literacy, local repair economies, and shared ownership models. From a theoretical standpoint, this finding reinforces RUDSHAM’s emphasis on Community Participation (CoP) as an indispensable driver of rural energy sustainability.

13.1.3 Technology Governance and E-Waste Crisis

While much focus has been placed on solar PV diffusion, Article 4 uncovers an emerging and largely neglected crisis: the proliferation of solar e-waste in off-grid communities. Saturated with counterfeit and substandard products, rural Zambia is witnessing a surge in broken panels, batteries, and accessories that are informally buried, burned, or repurposed, posing serious health and environmental risks.

Low literacy levels and a lack of technical awareness/capacity severely limit users’ ability to assess product quality, engage with warranty processes, or dispose of components safely. RUDSHAM’s attributes of Perceived Behavioural Control (PBC) and Policy Support (PS) help explain how weak regulation, poor information flows, and market deception fuel this problem. Additionally, the absence of any formal solar e-waste management infrastructure or legislation compounds the issue.

Theoretically, this expands the concept of energy justice to include post-adoption and end-of-life challenges, broadening the field's understanding of technology transitions beyond deployment metrics. Practically, the findings demand urgent action from policymakers to integrate e-waste governance into Zambia’s clean energy strategy, with user-centred regulation, solar repair hubs, and inclusive take-back schemes.

13.1.4 Role of Informal Market Actors

A novel contribution of this research is its in-depth examination of non-traditional actors in rural energy transitions, especially White commercial farmers (WCFs), explored in depth within Article 5. Far from being passive landholders, WCFs can play active roles in solar financing, community infrastructure provision, and conservation advocacy. They act as intermediaries between local communities and external investors or government actors and provide informal energy support to workers and neighbouring households.

This finding challenges conventional development narratives that often simplistically frame external commercial actors as peripheral or exploitative. While risks of power asymmetries exist, the research reveals that with appropriate regulation and participatory planning, WCFs can serve as agents of local resilience and infrastructure modernisation.

RUDSHAM's flexibility in accommodating such actors demonstrates its robustness in modelling pluralistic energy landscapes, where adoption is influenced not only by households and state institutions, but also by agricultural entrepreneurs, religious leaders, and community-based cooperatives. Policy implications include the integration of WCFs into national solar policy via land-leasing partnerships, security co-design, and environmental stewardship incentives.

13.1.5 Solar PV and Livelihood Trade-offs

The relationship between solar PV and rural livelihoods is complex and multi-dimensional. On the one hand, access to clean, reliable energy has resulted in enhanced wellbeing, including safer lighting, improved education (via night-time study), and extended business hours. On the other hand, Articles 6 and 7 caution against the ecological and social risks of funding solar access through intensified extraction of Non-Timber Forest Products (NTFPs).

Income from honey, mushrooms, bushmeat, and mopane worms has enabled many households to purchase solar systems. However, this commercialisation also leads to overharvesting, intra-community conflict, and threats to food security. The sustainability of solar transitions, therefore, depends not just on technological efficiency, but on the viability and governance of the income streams supporting adoption.

The RUDSHAM framework, especially through attributes like Green Concern (GC), Economic Cost (EC), and Prior Preferences and Practices (PP), illuminates these trade-offs. The findings suggest that balancing solar diffusion with sustainable livelihoods will require policy support for regulated NTFP markets, value chain development, and alternative income-generating opportunities such as agro-processing or eco-tourism.

13.1.6 Theoretical and Practical Advancements

Collectively, these studies advance the field of rural energy research in developing countries in three important ways:

i. Conceptual Innovation
   The development and operationalisation of the RUDSHAM framework represents a significant theoretical contribution. By integrating TAM, TPB, Diffusion of Innovation, and Social Learning Theory within a rural development context, RUDSHAM offers a novel, holistic framework adaptable across diverse geographies. It moves beyond behavioural intention to include governance,

environmental, and community participation factors, providing a more realistic and multi-layered tool for understanding energy transitions.

ii. Empirical Grounding
The research contributes context-specific evidence from underrepresented rural communities, particularly in Zambia, where empirical data on off-grid solar, e-waste, and community-led transitions remain sparse. It provides a rare longitudinal and multi-site account of how rural actors navigate, adapt, and shape decentralised energy systems.

iii. Policy Relevance
Each study offers actionable recommendations tailored to Zambia’s socio-political landscape. Whether it’s reconciling deforestation with solar finance, integrating e-waste into clean energy governance, or incentivising WCFs’ involvement, the research bridges theory and practice. The RUDSHAM framework is also a pragmatic tool for policymakers designing interventions that require nuanced understanding of local social dynamics and structural barriers.

13.1.7 Towards Just Energy Transition

This thesis demonstrates that solar PV adoption in rural Zambia is not merely a technical issue, but one deeply interwoven with questions of equity, ecology, agency, and governance. It challenges linear models of development and instead presents an account of energy transitions as contested, negotiated, and situated processes.

From the environmental paradox of solar financing via deforestation to the social learning dynamics of peer led adoption, the research reveals the messy realities and transformative potentials of decentralised energy. By applying and refining the RUDSHAM framework across seven studies, the work contributes a robust theoretical and methodological framework that deepens our understanding of energy transitions in Sub-Saharan Africa.

The findings collectively affirm that achieving sustainable and equitable rural development will require an integrated, participatory, and interdisciplinary approach. Only by acknowledging the trade-offs, leveraging local knowledge, and embedding policy in community contexts can the promise of solar PV truly contribute to an inclusive, resilient, and just energy future.

13.2 Synthesis of Research Questions, Objectives and Contributions

This section synthesises how the seven articles collectively address the research questions and achieve the stated research objectives. It also makes explicit the theoretical, empirical, methodological, and policy contributions of the study.

13.2.1 Answering the Research Questions

13.2.1.1 Research Question 1:

How does the expansion of solar photovoltaic technology in rural Zambia interact with existing patterns of biomass energy use, particularly charcoal dependence, and what are the resulting implications for deforestation, environmental sustainability, and national energy transition policy.

This question is principally answered through Article 1, Energy transitions in Sub-Saharan Africa: Policy recommendations for charcoal trade, solar PV adoption, and sustainability in rural Zambia and Article 2, The African clean energy deforestation paradox: Examining the sustainability trade-offs of rural solar energy expansion in Zambia. These articles demonstrate that solar PV adoption is frequently financed through charcoal production and intensified extraction of non-timber forest products, thereby creating the Clean Energy - Deforestation Paradox described in the study. The Forest to Solar Economic Trade-off Ratio, developed in Article 1, provides quantitative evidence of the scale of forest loss associated with solar financing, while Article 2 deepens the qualitative analysis of livelihood strategies and environmental impacts. Together, they show that solar expansion is embedded within existing biomass based economies and cannot be treated as an environmentally neutral transition. The question is therefore answered in full, with clear implications for integrated forestry and energy policy.

13.2.1.2 Research Question 2:

In what ways do community driven adoption pathways, including social learning, peer influence, and local ownership structures, shape the uptake, maintenance, and long-term sustainability of solar photovoltaic systems in rural Zambia, and how do these processes align with or diverge from externally designed interventions.

This question is addressed primarily by Article 3, Community Led Solar Energy Technology Adoption in Rural Zambia: The Role of Observational Learning and Neighbour Influence. The article shows that observational learning, neighbour imitation, and trusted local champions play decisive roles in decisions to adopt, upgrade, and maintain solar systems. It reveals that these community-based processes frequently diverge from external project designs and awareness campaigns, which tend to assume linear information flows from formal actors to households. In the RUDSHAM framework, this question is answered through the operationalisation of social learning, community participation, and local ownership attributes, which demonstrate that sustained use is closely tied to peer networks and informal governance rather than to one off interventions. The question is therefore substantiated with rich empirical evidence and theoretical elaboration.

13.2.1.3 Research Question 3:

What challenges are associated with the lifecycle management of solar photovoltaic systems in rural Zambia, particularly in relation to informal waste disposal practices, low levels of technical and consumer literacy, and the circulation of counterfeit or substandard technologies.

Research Question 3 is directly answered in Article 4, The solar E-waste challenge: A Zambian case study of informal disposal, counterfeit technologies and low literacy. This article documents informal disposal practices, widespread burial and burning of damaged components, the presence of counterfeit products, and limited understanding of warranties and safe handling. It demonstrates how low literacy and weak market regulation interact to create a growing stream of unmanaged solar waste, thus extending debates on energy transitions into end of life governance. The findings provide a comprehensive response to the research question by identifying specific behavioural, institutional, and infrastructural barriers to responsible lifecycle management.

13.2.1.4 Research Question 4:

How do nontraditional energy actors, including White commercial farmers and self-financing rural households, influence the accessibility, distribution, and developmental outcomes of decentralised solar photovoltaic systems in off-grid rural regions.

This question is answered mainly by Article 5, Exploring the nexus of solar adoption, sustainability, and rural community development through the role of White commercial farmers: The case of Mkushi, Zambia and supported by findings from Articles 1, 6, and 7. Article 5 shows that White commercial farmers can act as financiers, infrastructure providers, and intermediaries in local solar markets, shaping who gains access to energy and under what conditions. It also documents their influence on security arrangements, land use, and community level infrastructure such as boreholes and distribution lines. The role of self-financing households, often drawing on forest-based incomes, is highlighted in Articles 2, 6, and 7, which together show how non state actors drive adoption in the absence of formal programmes. The question is thus addressed by demonstrating that nontraditional actors are central, rather than peripheral, to rural energy transitions.

13.2.1.5 Research Question 5:

To what extent does solar photovoltaic adoption support or undermine rural livelihood strategies in Zambia, particularly through its interaction with non-timber forest products such as honey, mushrooms, and traditional beer production, as well as seasonal income generating activities.

This question is answered in depth through Article 6, Nexus Between Solar PV Adoption and Wild Food Sustainability: Case of Income from Honey, Fruits, Traditional Beer, and Vegetables in Rural Zambia and Article 7, Environmental and social impacts of self-financed solar PV adoption in rural Zambia: Insights from mopane worms, mushrooms, fishing, bushmeat and ethnomedicine. These articles show that solar adoption can enhance some livelihood activities by extending working hours, improving safety, and enabling new services, yet it can also intensify pressure on forest and wildlife resources when households rely on these for solar financing. The evidence demonstrates both supportive and undermining effects on livelihoods and thereby answers the question by presenting a nuanced picture of livelihood trade-offs.

Taken together, the seven articles fully address all five research questions, with each question supported by multiple converging strands of evidence.

13.2.2 Achievement of the Research Objectives

13.2.2.1 Objective 1:

To examine the environmental and energy transition dynamics linked to solar PV expansion in rural Zambia, particularly in relation to the country's reliance on biomass fuels like charcoal, and its implications for deforestation, energy policy, and sustainability.

This objective is achieved primarily through Articles 1 and 2, with additional insights from Articles 6 and 7. The empirical findings demonstrate how charcoal production and forest product extraction are directly linked to the financing of solar PV systems and quantify the environmental trade-offs involved. Policy recommendations in Article 1 further address national energy and forestry policy, thereby meeting the objective in both analytical and policy terms.

13.2.2.2 Objective 2:

To explore the role of community driven adoption pathways including social learning, peer influence, and local ownership structures in supporting or limiting the uptake, use, and maintenance of solar PV systems, and how these align or conflict with external supply side interventions.

This objective is met through Article 3 and is reinforced by cross cutting evidence from the other articles where community narratives, peer dynamics, and local governance arrangements are examined. Article 3 provides a detailed account of observational learning, neighbour influence, and local leadership, while the wider thesis shows mismatches between externally planned interventions and community driven practices. The objective is therefore fully addressed.

13.2.2.3 Objective 3:

To assess the emerging challenges related to solar PV waste and system reliability in rural Zambia, focusing on the effects of low consumer literacy, unregulated disposal practices, and the influx of counterfeit or substandard solar technologies.

Article 4 directly fulfils this objective by documenting the nature and scale of solar e-waste, the prevalence of counterfeit technologies, and the knowledge gaps that hinder safe disposal. The analysis identifies specific regulatory and educational shortcomings and offers concrete recommendations for e-waste governance. The objective is therefore comprehensively achieved.

13.2.2.4 Objective 4:

To investigate the roles played by non-traditional energy actors, including White commercial farmers and self-financing rural households, in facilitating or obstructing solar PV access, community development, and infrastructure improvement in off-grid regions.

This objective is realised through Article 5 in combination with supporting evidence from Articles 1, 2, 6, and 7. The thesis shows that White commercial farmers can facilitate infrastructure development and access to energy, while self-financing households play a critical role in driving demand under conditions of limited formal support. At the same time, the research acknowledges the risks of exclusion and power asymmetries, thereby offering a balanced assessment of facilitation and obstruction.

13.2.2.5 Objective 5:

To analyse the extent to which solar PV adoption supports or undermines rural livelihoods, with a particular focus on its integration with non-timber forest products such as honey, mushrooms, traditional beer and seasonal income generating activities in Zambia's rural communities.

Articles 6 and 7 collectively achieve this objective by providing detailed empirical accounts of how solar PV adoption intersects with wild food harvesting, income generation, and environmental sustainability. The findings show both livelihood improvements and ecological risks, thereby fulfilling the objective through a nuanced analysis of support and undermining effects.

All five research objectives are achieved through the combined empirical and analytical contributions of the seven articles, with each objective addressed by at least one primary article and supported by cross cutting insights from the wider thesis.

13.2.3 Contributions of the Study

This thesis makes three main types of contribution as follows.

13.2.3.1 Theoretical contributions

First, the development and application of the Rural Development Stakeholder Hybrid Adoption Model represents a significant conceptual advance. By integrating existing theoretical strands within a rural development and energy transition context, RUDSHAM provides a comprehensive framework for understanding how behavioural, social, institutional, and environmental factors interact in decentralised energy systems. The framework moves beyond intention based approaches to incorporate governance, livelihoods, and environmental trade-offs, thereby enriching theoretical debates on energy transitions in rural Sub-Saharan settings.

13.2.3.2 Empirical contributions

Second, the thesis contributes original empirical evidence from rural communities in Zambia that have been underrepresented in the literature. It documents the Clean

Energy - Deforestation Paradox, uncovers an emerging solar e-waste challenge in off-grid contexts, and provides rare insights into the roles of White commercial farmers and forest based livelihoods in shaping solar adoption. The multi site qualitative design, based on extensive interviews, focus groups, and participant observation, offers a textured and context specific understanding of how rural actors experience and shape solar transitions.

13.2.3.3 Policy and practice contributions

Third, the research provides actionable guidance for policy and practice. Across the seven articles, it puts forward recommendations on integrating forestry and energy policy, designing community centred solar programmes, regulating counterfeit technologies, and engaging non traditional actors in inclusive and accountable ways. The work shows how national strategies and community practices can be better aligned so that solar PV adoption contributes to sustainable livelihoods rather than exacerbating environmental and social vulnerabilities.

13.3 Future Research Directions and Study Limitations

13.3.1 Future Research Directions

Future research should prioritise longitudinal and geographically diverse studies to capture the evolving dynamics of solar PV adoption, especially the seasonal patterns of forest-product financing and e-waste disposal. A year-round design would better illuminate the relationship between agricultural cycles, income fluctuations, and technology use. Greater attention must also be given to governance mechanisms, particularly the integration of clean energy and policy on forest products. This includes evaluating the impact of urban energy interventions on rural deforestation, and the institutional alignment necessary to address the charcoal-solar paradox.

The gendered nature of energy transitions deserves deeper scrutiny. Future work should investigate the socio-economic barriers women face in the charcoal trade and NTFP value chains, with a view to enhancing their access to sustainable energy and alternative livelihoods. Moreover, solar e-waste governance remains an under-researched area. Future studies could explore the cultural and economic logics underpinning informal disposal practices and the uptake of counterfeit products, using participatory and ethnographic methods. Evaluating the impact of localised solar literacy campaigns would provide practical insights for community-based energy education.

Finally, building on the novel contributions of the RUDSHAM framework, further research should test its applicability in other rural Sub-Saharan African contexts and examine the role of non-traditional actors, such as White commercial farmers, in decentralised solar transitions.

13.3.2 Research Limitations

This research was largely exploratory and constrained by relatively short fieldwork durations, which may not fully reflect seasonal or long-term trends. Additionally, sampling coverage was limited to selected rural districts due to logistical and funding constraints. Nonetheless, these strategically chosen sites offered rich and policy-relevant insights into Zambia's evolving rural energy landscape.

References

Abass, A., Amaza, P., Bachwenkizi, B., Alenkhe, B., Mukuka, I., Cromme, N., 2017. Adding value through the mechanization of post-harvest cassava processing, and its impact on household poverty in north-eastern Zambia. Appl. Econ. Lett. 24, 579–583. https://doi.org/10.1080/13504851.2016.1213356

Aboagye, S., Adjei Kwakwa, P., 2023. The role of international tourism, trade openness and renewable energy in the financial development of selected African countries. Res. Glob. 7, 100170. https://doi.org/10.1016/J.RESGLO.2023.100170

Aborisade, R.A., Adedayo, S.S., 2021. 'Catch me if you can': the myth and reality of criminals' use of juju to evade arrest from the Nigeria police. Police Pract. Res. 22, 74–89.

Abro, Z., Kassie, M., Tiku, H.A., Taye, B., Ayele, Z.A., Ayalew, W., 2022. The impact of beekeeping on household income: evidence from north-western Ethiopia. Heliyon 8, e09492. https://doi.org/10.1016/j.heliyon.2022.e09492

Adams, S., Asante, W., 2020. Politics of Renewable Energy in Africa: Nature, Prospects, and Challenges. Innov. Glob. Green Technol. 2020. https://doi.org/10.5772/INTECHOPEN.89019

Addi, A., Bareke, T., 2014. Contribution of Beekeeping to the Income Generation of the Households bordering Menagesha suba State Forest , Ethiopia. Conf. Pap. 45–67.

Adelhardt, N., Berneiser, J., 2024. Risk analysis for agrivoltaic projects in rural farming communities in SSA. Appl. Energy 362, 122933. https://doi.org/10.1016/j.apenergy.2024.122933

Adewumi, M.O., Jimoh, A., Omotesho, O.A., 2013. Analysis of the effects of Zimbabwean white farmers on small scale farming in Nigeria. Acta Univ. 23, 3–7. https://doi.org/10.15174/au.2013.408

Adhikari, B., Kang, S.S.Y., Dahal, A., Mshamu, S., Deen, J., Pell, C., von Seidlein, L., Knudsen, J., Bøjstrup, T.C., 2025. Acceptability of improved cook stoves-a scoping review of the literature. PLOS Glob. Public Heal. 5, 1–21. https://doi.org/10.1371/journal.pgph.0004042

Adjei, N.A., 2024. Effective Regulation and the Energy Transition in Zambia, in: Ackah, I., Gatete, C. (Eds.), Energy Regulation in Africa: Dynamics, Challenges, and Opportunities. Springer Nature Switzerland, Cham, pp. 151–167. https://doi.org/10.1007/978-3-031-52677-0_7

Agoundedemba, M., Kim, C.K., Kim, H.G., 2023. Energy Status in Africa: Challenges, Progress and Sustainable Pathways. Energies. https://doi.org/10.3390/en16237708

Ahmar, M., Ali, F., Jiang, Y., Alwetaishi, M., Ghoneim, S.S.M., 2022. Households' Energy Choices in Rural Pakistan. Energies 15. https://doi.org/10.3390/en15093149

Ajagun, A.S., Mao, W., Sun, X., Guo, J., Adebisi, B., Aibinu, A.M., 2024. The status and potential of regional integrated energy systems in sub-Saharan Africa: An Investigation of the feasibility and implications for sustainable energy development. Energy Strateg. Rev. 53, 101402. https://doi.org/https://doi.org/10.1016/j.esr.2024.101402

Ajayi, A.O., Agupugo, C.P., Nwanevu, C., Chimziebere, C., 2024. Review of penetration and impact of utility solar installation in developing countries : policy and challenges Review of penetration and impact of utility solar installation in developing countries : policy and challenges 10–24. https://doi.org/10.53294/ijfetr.2024.7.2.0046

Ajzen, I., 1991. The theory of planned behavior. Organ. Behav. Hum. Decis. Process. 50, 179–211. https://doi.org/10.1016/0749-5978(91)90020-T

Aker, J.C., Jack, K., 2021. Harvesting the Rain: The Adoption of Environmental Technologies in the Sahel.

Akinnifesi, F.K., Kwesiga, F.R., Mhango, J., Mkonda, A., Chilanga, T., Swai, R., 2004. Domesticating priority for miombo indigenous fruit trees as a promising livelihood option for small-holder farmers in Southern Africa. Acta Hortic. 632, 15–30. https://doi.org/10.17660/actahortic.2004.632.1

Alexander, J.S., McNamara, J., Rowcliffe, J.M., Oppong, J., Milner-Gulland, E.J., 2015. The role of bushmeat in a West African agricultural landscape. Oryx 49, 643–651. https://doi.org/10.1017/S0030605313001294

Alfaro, J.F., Miller, S.A., 2021. Analysis of electrification strategies for rural renewable electrification in developing countries using agent-based models. Energy Sustain. Dev. 61, 89–103. https://doi.org/10.1016/j.esd.2021.01.004

Alipour, M., Salim, H., Stewart, R.A., Sahin, O., 2021. Residential solar photovoltaic adoption behaviour: End-to-end review of theories, methods and approaches. Renew. Energy 170, 471–486. https://doi.org/10.1016/j.renene.2021.01.128

Amadu, F.O., Miller, D.C., 2024. The impact of forest product collection and processing on household income in rural Liberia. For. Policy Econ. 158, 103098. https://doi.org/10.1016/j.forpol.2023.103098

Ambole, A., Koranteng, K., Njoroge, P., Luhangala, D.L., 2021. A review of energy communities in sub-saharan africa as a transition pathway to energy democracy. Sustain. 13, 1–19. https://doi.org/10.3390/su13042128

Ameli, N., Dessens, O., Winning, M., Cronin, J., Chenet, H., Drummond, P., Calzadilla, A., Anandarajah, G., Grubb, M., 2020. A climate investment trap in developing economies. https://doi.org/10.21203/rs.3.rs-119752/v1

Amjath-Babu, T.S., Krupnik, T.J., Kaechele, H., Aravindakshan, S., Sietz, D., 2016. Transitioning to groundwater irrigated intensified agriculture in Sub-Saharan Africa: An indicator based assessment. Agric. Water Manag. 168, 125–135. https://doi.org/10.1016/J.AGWAT.2016.01.016

Amusa, T., Avana-Tientcheu, M.L., Awazi, N.P., Chirwa, P., 2024. The Role of Non-Timber Forest Products for Sustainable Livelihoods in African Multifunctional Landscapes, in: Trees in a Sub-Saharan Multi-Functional Landscape. pp. 153–178. https://doi.org/10.1007/978-3-031-69812-5_8

Amuzu-Sefordzi, B., Martinus, K., Tschakert, P., Wills, R., 2018. Disruptive innovations and decentralized renewable energy systems in Africa: A socio-technical review. Energy Res. Soc. Sci. 46, 140–154. https://doi.org/10.1016/j.erss.2018.06.014

Andrews, M., Pritchett, L., Woolcock, M., 2017. Building State Capability: Evidence, Analysis, Action, First. ed. Oxford University Press, Oxford.

Antwi, S.H., Ley, D., 2021. Renewable energy project implementation in Africa: Ensuring sustainability through community acceptability. Sci. African 11, e00679. https://doi.org/10.1016/J.SCIAF.2020.E00679

Anyango, S.O., Mbewe, B., Nangavo, V.S., Mwal, M., 2018. Towards Sustainable Livelihood Practices in the Indigenous Forests of Zambia's Central Province: Barriers and Opportunities. Energy Environ. Res. 8, 1. https://doi.org/10.5539/eer.v8n2p1

Aquaron, R., Djatou, M., Kamdem, L., 2009. Sociocultural aspects of albinism in sub-Saharan Africa: Mutilations and ritual murders committed in east Africa (Burundi and Tanzania). Med. Trop. (Mars). 69, 449–453.

Arko, T., Mensah, A., Adomako, J., Denton, F., Obani, P., 2024. The multifaceted socio-ecological impacts of charcoal production on the Afram Plains, Ghana. Trees, For. People 16, 100586. https://doi.org/10.1016/j.tfp.2024.100586

Arumugam, S., Govindasamy, R., E. Simon, J., Wyk, E. Van, Chali, K., Mbewe, M., Siziya, I., Weller, S., K. Morin, X., 2020. African Indigenous Vegetables Production and Consumption Behavior of Farmers in Zambia: An Econometric Analysis. Tech. Soc. Sci. J. 8, 220–228. https://doi.org/10.47577/tssj.v8i1.598

Avis, W., 2021. Drivers, barriers and opportunities of e-waste management in Africa. Inst. Dev. Stud. 1074, 2–27. https://doi.org/https://doi.org/10.19088/K4D.2022.016

Awad, A., Warsame, M.H., 2022. The poverty-environment nexus in developing countries: Evidence from heterogeneous panel causality methods, robust to cross-sectional dependence. J. Clean. Prod. 331, 129839. https://doi.org/https://doi.org/10.1016/j.jclepro.2021.129839

Axon, S., 2020. The socio-cultural dimensions of community-based sustainability: Implications for transformational change. J. Clean. Prod. 266, 121933. https://doi.org/10.1016/J.JCLEPRO.2020.121933

Azimoh, C.L., Klintenberg, P., Mbohwa, C., Wallin, F., 2017. Replicability and scalability of mini-grid solution to rural electrification programs in sub-Saharan Africa. Renew. Energy 106, 222–231. https://doi.org/10.1016/J.RENENE.2017.01.017

Bai, B., Xiong, S., Ma, X., Tian, Y., 2021. Effectiveness evaluation of photovoltaic poverty alleviation project in China: From a capital perspective. J. Clean. Prod. 284, 124684. https://doi.org/10.1016/J.JCLEPRO.2020.124684

Balmes, J., 2015. Indoor Biomass Burning and Health Consequences. pp. 381–402. https://doi.org/10.1007/978-1-4471-6669-6_14

Baltruszewicz, M., Steinberger, J.K., Owen, A., Brand-Correa, L.I., Paavola, J., 2021.

Final energy footprints in Zambia: Investigating links between household consumption, collective provision, and well-being. Energy Res. Soc. Sci. 73. https://doi.org/10.1016/j.erss.2021.101960

Bandura, A., 1977. Social learning theory. General Learning Press. https://doi.org/https://ia601807.us.archive.org/14/items/BanduraSocialLearningTheory/Bandura_SocialLearningTheory_text.pdf

Banik, D., 2021. Chapter 7 - The 2030 agenda and the push for electrification in Africa: a tale of two countries, in: Singh, P., Verma, P., Perrotti, D., Srivastava, K.K. (Eds.), Environmental Sustainability and Economy. Elsevier, pp. 121–136. https://doi.org/https://doi.org/10.1016/B978-0-12-822188-4.00011-7

Barke, A., 2023. Poverty in Africa: Causes, Consequences, and Potential Solutions, International Journal of Science and Society.

Barman, M., Mahapatra, S., Palit, D., Chaudhury, M.K., 2017. Performance and impact evaluation of solar home lighting systems on the rural livelihood in Assam, India. Energy Sustain. Dev. 38, 10–20. https://doi.org/10.1016/J.ESD.2017.02.004

Barr, S., Shaw, G., Coles, T., Prillwitz, J., 2010. “A holiday is a holiday”: practicing sustainability, home and away. J. Transp. Geogr. 18, 474–481. https://doi.org/10.1016/j.jtrangeo.2009.08.007

Barrie, J., Cruickshank, H.J., 2017. Shedding light on the last mile: A study on the diffusion of Pay As You Go Solar Home Systems in Central East Africa. Energy Policy 107, 425–436. https://doi.org/10.1016/J.ENPOL.2017.05.016

Bates, M., Osibanjo, O., 2019. Chapter 5. Management of Electronic Waste in Africa, in: Management of Electronic Waste in Africa. pp. 137–165. https://doi.org/10.1039/9781788018784-00137

Batidzirai, B., Trotter, P.A., Brophy, A., Stritzke, S., Moyo, A., Twesigye, P., Puranasamriddhi, A., Madhlopa, A., 2021a. Towards people-private-public partnerships: An integrated community engagement model for capturing energy access needs. Energy Res. Soc. Sci. 74, 101975. https://doi.org/10.1016/J.ERSS.2021.101975

Batidzirai, B., Trotter, P.A., Brophy, A., Stritzke, S., Moyo, A., Twesigye, P., Puranasamriddhi, A., Madhlopa, A., 2021b. Towards people-private-public partnerships: An integrated community engagement model for capturing energy access needs. Energy Res. Soc. Sci. 74, 101975. https://doi.org/10.1016/J.ERSS.2021.101975

Batisai, K., Mudimu, G.T., 2021. Revisiting the Politics of Land Recovery among White Commercial Farmers in Zimbabwe: Implications for Transitional Justice. Int. J. Transit. Justice 15, 370–385. https://doi.org/10.1093/ijtj/ijab010

Baurzhan, S., Jenkins, G.P., 2016. Off-grid solar PV: Is it an affordable or appropriate solution for rural electrification in Sub-Saharan African countries? Renew. Sustain. Energy Rev. 60, 1405–1418. https://doi.org/10.1016/j.rser.2016.03.016

Bauwens, T., Schraven, D., Drewing, E., Radtke, J., Holstenkamp, L., Gotchev, B., Yildiz, Ö., 2022. Conceptualizing community in energy systems: A systematic review of 183 definitions. Renew. Sustain. Energy Rev. 156, 111999. https://doi.org/10.1016/j.rser.2021.111999

Baye, R.S., Ahenkan, A., Darkwah, S., 2021. Renewable energy output in sub Saharan Africa. Renew. Energy 174, 705–714. https://doi.org/10.1016/J.RENENE.2021.01.144

Bayliss, K., Pollen, G., 2021. The power paradigm in practice: A critical review of developments in the Zambian electricity sector. World Dev. 140. https://doi.org/10.1016/j.worlddev.2020.105358

Belligoni, S., Trader, E., Li, M., Rahman, M.S., Ali, J., Enriquez, A.R., Nagaraj, M., Aksha, S.K., Stevens, K.A., Wahl, T., Emrich, C.T., Qu, Z., Davis, K.O., 2025. Transdisciplinary research promoting clean and resilient energy systems for socially vulnerable communities: A review. Renew. Sustain. Energy Rev. 213, 115434. https://doi.org/https://doi.org/10.1016/j.rser.2025.115434

Bernhard, P., 2019. Non-timber Forest Products. Environ. Sci.

Bhatasara, S., Nwosu, C., Macheka, L., Nyamwanza, A.M., 2025. Narratives of climate adaptation and linkages to psychosocial and nutritional health in a Zimbabwean rural community. World Dev. Sustain. 6, 100205. https://doi.org/10.1016/j.wds.2025.100205

Bhattacharyya, S.C., Palit, D., 2021. A critical review of literature on the nexus between central grid and off-grid solutions for expanding access to electricity in Sub-Saharan Africa and South Asia. Renew. Sustain. Energy Rev. 141, 110792. https://doi.org/10.1016/J.RSER.2021.110792

Bitzer, V., Moździerz, M., Kuijpers, R., Schouten, G., Juju, D.B., 2024. Gender and forest resources in low- and middle-income countries: A systematic literature review. For. Policy Econ. 163. https://doi.org/10.1016/j.forpol.2024.103226

Blimpo, M.P., Postepska, A., Xu, Y., 2020. Why is household electricity uptake low in Sub-Saharan Africa? World Dev. 133, 1–41. https://doi.org/10.1016/j.worlddev.2020.105002

Borah, R.R., Palit, D., Mahapatra, S., 2014. Comparative Analysis of Solar Photovoltaic Lighting Systems in India. Energy Procedia 54, 680–689. https://doi.org/10.1016/J.EGYPRO.2014.07.309

Boukandou Mounanga, M., Mewono, L., Aboughe Angone, S., 2015. Toxicity studies of medicinal plants used in sub-Saharan Africa. J. Ethnopharmacol. 174, 618–627. https://doi.org/10.1016/j.jep.2015.06.005

Branch, A., Phillips, J., Agyei, F.K., 2023. Charcoal politics in Africa: Value chains, resource complexes, and energopolitics. Prog. Environ. Geogr. 2, 77–96. https://doi.org/10.1177/27539687231165798

Brown, T., Marks, S.A., 2008. Livelihoods, Hunting and the Game Meat Trade in Northern Zambia. Bushmeat Livelihoods Wildl. Manag. Poverty Reduct. 92–105. https://doi.org/10.1002/9780470692592.ch6

Brugger, H.I., Henry, A.D., 2019. Equity of Incentives: Agent-Based Explorations of How Social Networks Influence the Efficacy of Programs to Promote Solar

Adoption. Complexity 2019. https://doi.org/10.1155/2019/4349823

Brunet, C., Savadogo, O., Baptiste, P., Bouchard, M.A., 2018. Shedding some light on photovoltaic solar energy in Africa – A literature review. Renew. Sustain. Energy Rev. 96, 325–342. https://doi.org/10.1016/j.rser.2018.08.004

Budzianowski, W.M., Nantongo, I., Bamutura, C., Rwema, M., Lyambai, M., Abimana, C., Akumu, E.O., Alokore, Y., Babalola, S.O., Gachuri, A.K.K., Hefney Diab, M.S., Ituze, G., Kiprono, H., Kouakou, G.C., Kukeera, T., Megne, W.B., Muceka, R., Mugumya, A., d.Amour Mwongereza, J., Nwadiaru, O. V, Sow, S., 2018. Business models and innovativeness of potential renewable energy projects in Africa. Renew. Energy 123, 162–190. https://doi.org/10.1016/j.renene.2018.02.039

Butu, H.M., Nsafon, B.E.K., Park, S.W., Huh, J.S., 2021. Leveraging community based organizations and fintech to improve small-scale renewable energy financing in sub-Saharan Africa. Energy Res. Soc. Sci. https://doi.org/10.1016/j.erss.2021.101949

Bvenura, C., Sivakumar, D., 2017. The role of wild fruits and vegetables in delivering a balanced and healthy diet. Food Res. Int. 99, 15–30. https://doi.org/10.1016/j.foodres.2017.06.046

Bwalya, R., Zulu, M., 2021. The Role of Savings Group on the Nutritional and Economic Wellbeing of Rural Households: The Case of World Vision's Savings for Transformation (S4T) in Zambia. Bus. Econ. Res. https://doi.org/10.5296/ber.v11i2.18451

Byaro, M., Mmbaga, N.F., Mafwolo, G., 2024. Tackling energy poverty: Do clean fuels for cooking and access to electricity improve or worsen health outcomes in sub-Saharan Africa? World Dev. Sustain. 4, 100125. https://doi.org/10.1016/J.WDS.2024.100125

Care, O.G., 2020. Village Savings and Loan Associations Tim Mwaura/CARE.

Carpio-Domínguez, J.L., 2024. The Harms and Crimes of Logging and Deforestation. https://doi.org/10.1093/acrefore/9780190264079.013.769

Cerutti, P.., D.J., G., K.B., M., G.C., S., R., N., N., B., X., W., 2018. Mukula (rosewood) trade between China and Zambia. Mukula (rosewood) trade between China and Zambia. https://doi.org/10.17528/cifor/006880

Chambalile, M., Su, B., Phiri, X., Huan, J., 2024. Maximizing Solar Integration: Enhancing Off-grid Rural Energy Storage in Zambia. J. Eng. Res. Reports 26, 273–282. https://doi.org/10.9734/jerr/2024/v26i51153

Chanda, H., Mohareb, E., Peters, M., Harty, C., 2025a. Community-led solar energy technology adoption in rural Zambia : The role of observational learning and neighbor influence. Energy Res. Soc. Sci. 122, 103972. https://doi.org/10.1016/j.erss.2025.103972

Chanda, H., Mohareb, E., Peters, M., Harty, C., 2025b. Environmental and social impacts of self-financed solar PV adoption in rural Zambia: Insights from mopane worms, mushrooms, fishing, bushmeat and ethnomedicine. Energy Sustain. Dev. 85, 101665. https://doi.org/10.1016/j.esd.2025.101665

Chanda, H., Mohareb, E., Peters, M., Harty, C., 2025c. Nexus between solar-PV adoption and wild food sustainability : Case of income from honey , fruits , traditional-beer , and vegetables in rural Zambia. Energy Sustain. Dev. 85, 101694. https://doi.org/10.1016/j.esd.2025.101694

Chanda, H., Mohareb, E., Peters, M., Harty, C., 2025d. “The solar E-waste challenge: A zambian case study of informal disposal, counterfeit technologies and low literacy.” J. Environ. Manage. 395, 127618. https://doi.org/https://doi.org/10.1016/j.jenvman.2025.127618

Chanda, H., Mohareb, E., Peters, M., Harty, C., 2025e. Exploring the nexus of solar adoption, sustainability, and rural community development through the role of white commercial farmers: The case of Mkushi, Zambia. Energy Res. Soc. Sci. 128, 104336. https://doi.org/10.1016/j.erss.2025.104336

Chanda, H., Mohareb, E., Peters, M., Harty, C., 2025f. Exploring the nexus of solar adoption , sustainability , and rural community development through the role of white commercial farmers : The case of. Energy Res. Soc. Sci. 128, 104336. https://doi.org/10.1016/j.erss.2025.104336

Chanda, H., Mohareb, E., Peters, M., Harty, C., Green, M., Kasanda, E.B., Shibata, N., 2026. Energy transitions in Sub-Saharan Africa: Policy recommendations for charcoal trade, solar PV adoption, and sustainability in rural Zambia. Energy Policy 208, 114936. https://doi.org/https://doi.org/10.1016/j.enpol.2025.114936

Chanda, H., Mohareb, E., Peters, M., Harty, C., Green, M., Shibata, N., Kasanda, E.B., 2025g. “The African clean energy-deforestation paradox: Examining the sustainability trade-offs of rural solar energy expansion in Zambia.” Energy Res. Soc. Sci. 129, 104389. https://doi.org/https://doi.org/10.1016/j.erss.2025.104389

Chandel, S.S., Nagaraju Naik, M., Chandel, R., 2015. Review of solar photovoltaic water pumping system technology for irrigation and community drinking water supplies. Renew. Sustain. Energy Rev. 49, 1084–1099. https://doi.org/10.1016/J.RSER.2015.04.083

Chang, K.C., Hagumimana, N., Zheng, J., Asemota, G.N.O., Niyonteze, J.D.D., Nsengiyumva, W., Nduwamungu, A., Bimenyimana, S., 2021. Standalone and Minigrid-Connected Solar Energy Systems for Rural Application in Rwanda: An in Situ Study. Int. J. Photoenergy 2021. https://doi.org/10.1155/2021/1211953

Chaurey, A., Krithika, P.R., Palit, D., Rakesh, S., Sovacool, B.K., 2012. New partnerships and business models for facilitating energy access. Energy Policy 47, 48–55. https://doi.org/10.1016/j.enpol.2012.03.031

Che, N.B., Nkemnyi, M.F., Atem, E.T., Giliba, R., 2017. The correlation between bushmeat harvesting and wildlife abundance in the Tofala-Mone Forest Corridor, Cameroon. Int. J. Conserv. Sci. 8, 465–474.

Chekol, F., Giera, M., Alemu, B., Dessie, M., Alemayehu, Y., Ewuinetu, Y., 2023. Rural Households’ Behaviour towards Modern Energy Technology Adoption Choices in East Gojjam Zone of Ethiopia: A Multivariate Probit Regression Analysis. Cogent Eng. 10. https://doi.org/10.1080/23311916.2023.2178107

Chidembo, R., Francis, J., Kativhu, S., 2024. Underlying beliefs that influence solar home system adoption in Vhembe district Municipality, South Africa. Soc. Sci.

Humanit. Open 9, 100754. https://doi.org/10.1016/j.ssaho.2023.100754

Chidembo, R., Francis, J., Kativhu, S., 2022. Rural Households' Perceptions of the Adoption of Rooftop Solar Photovoltaics in Vhembe District, South Africa. Energies 15, 0–11. https://doi.org/10.3390/en15176157

Chidumayo, E.N., Mbata, K.J., 2002. Shifting cultivation, edible caterpillars and livelihoods in the kopa area of Northern Zambia. For. Trees Livelihoods 12, 175–193. https://doi.org/10.1080/14728028.2002.9752423

Chikopela, L., Kalinda, T.H., Ng'ombe, J.N., Kuntashula, E., 2024. Cultivating sustainability: Adoption and intensity of soil fertility management technologies among rural farms in Zambia. World Dev. Sustain. 5. https://doi.org/10.1016/j.wds.2024.100174

Chikumbirike, J., Bamford, M.K., 2021. A Southern African Perspective on the Contribution of Charcoal Analyses to Archaeology. Oxford Res. Encycl. Anthropol. https://doi.org/10.1093/acrefore/9780190854584.013.257

Chileshe, M., 2023a. International Renewable Energy Finance Mechanisms and the Role of Local Stakeholders in Project Design and Implementation: Perceptions from Zambia. Open J. Bus. Manag. 11, 3066–3080. https://doi.org/10.4236/ojbm.2023.116168

Chileshe, M., 2023b. International Renewable Energy Finance Mechanisms and the Role of Local Stakeholders in Project Design and Implementation: Perceptions from Zambia. Open J. Bus. Manag. 11, 3066–3080. https://doi.org/10.4236/ojbm.2023.116168

Chinsembu, K.C., Syakalima, M., Semenya, S.S., 2019. Ethnomedicinal plants used by traditional healers in the management of HIV/AIDS opportunistic diseases in Lusaka, Zambia. South African J. Bot. 122, 369–384. https://doi.org/10.1016/j.sajb.2018.09.007

Chirambo, D., 2018. Towards the achievement of SDG 7 in sub-Saharan Africa: Creating synergies between Power Africa, Sustainable Energy for All and climate finance in-order to achieve universal energy access before 2030. Renew. Sustain. Energy Rev. 94, 600–608. https://doi.org/10.1016/J.RSER.2018.06.025

Chishaleshale, M., Chirwa, P.W., Zekeng, J.C., Syampungani, S., 2024. How do socio-economic characteristics of communities influence resource use and forest cover in the Cryptosepalum forest of North-western Zambia. Heliyon 10, e28658. https://doi.org/10.1016/j.heliyon.2024.e28658

Christian, M.Y., Kasumi, I., 2015. Trade of the most popular Indigenous fruits and nuts, threats and opportunities for their sustainable management around the Ivindo National Park (INP), Gabon. Int. J. Biodivers. Conserv. 7, 85–102. https://doi.org/10.5897/ijbc2014.0747

Chu, J., 2013. Creating a Zambian Breadbasket. 'Land grabs' and foreign investments in agriculture in Mkushi District, Zambia (No. 33), Land Deal Politics Initiative. https://doi.org/www.iss.nl/ldpi

Chungu, D., Muimba-Kankolongo, A., Roux, J., Malambo, F.M., 2007. Bark removal for medicinal use predisposes indigenous forest trees to wood degradation in Zambia. South. Hemisph. For. J. 69, 157–163. https://doi.org/10.2989/SHFJ.2007.69.3.4.354

Clean Cooking Alliance, 2025. Clean Cooking Alliance (CCA) Health Factsheet [WWW Document]. https://doi.org/https://cleancooking.org/the-issues/health/

Clube, R.K.M., Hazemba, M., 2024. From waste to resource: demystifying the policy challenges and identifying opportunities for a circular economy in Zambia. Front. Sustain. 5, 1–7. https://doi.org/10.3389/frsus.2024.1300904

Conway, D., Robinson, B., Mudimu, P., Chitekwe, T., Koranteng, K., Swilling, M., 2019. Exploring hybrid models for universal access to basic solar energy services in informal settlements: Case studies from South Africa and Zimbabwe. Energy Res. Soc. Sci. 56, 101202. https://doi.org/10.1016/j.erss.2019.05.012

Coy, D., Malekpour, S., Saeri, A.K., 2022. From little things, big things grow: Facilitating community empowerment in the energy transformation. Energy Res. Soc. Sci. 84, 102353. https://doi.org/10.1016/J.ERSS.2021.102353

Creamer, E., Taylor Aiken, G., van Veelen, B., Walker, G., Devine-Wright, P., 2019. Community renewable energy: What does it do? Walker and Devine-Wright (2008) ten years on. Energy Res. Soc. Sci. 57, 101223. https://doi.org/10.1016/J.ERSS.2019.101223

CSO, 2018. Compendium of Environment Statistics. Cent. Stat. Off. https://doi.org/https://unstats.un.org/unsd/environment/Compendia/Zambia_Compedium%20of%20Environment%20Statistics_2015.pdf

Cyril, A.O., Ujah, C.O., Ekwueme, B.N., Asadu, C.O., 2024. Photovoltaic mini-grid incorporation: The panacea for electricity crisis in sub-Saharan Africa. Unconv. Resour. 4, 100079. https://doi.org/10.1016/j.uncres.2024.100079

D’Souza, M., Govender, D., 2019. Starving for Data and More: What Rangers and Scientists Stand to Learn from One Another in South Africa. iBOL Barcode Bull. 9, 10–12. https://doi.org/10.21083/ibol.v9i1.5471

Dagnachew, A.G., Hof, A.F., Roelfsema, M.R., van Vuuren, D.P., 2020. Actors and governance in the transition toward universal electricity access in Sub-Saharan Africa. Energy Policy 143, 111572. https://doi.org/10.1016/J.ENPOL.2020.111572

Dario, 2020. Solar and wind energy can strengthen Zambia’s electricity supply.

Davidson, O., Mwakasonda, S.A., 2004. Electricity access for the poor: a study of South Africa and Zimbabwe. Energy Sustain. Dev. 8, 26–40. https://doi.org/10.1016/S0973-0826(08)60511-6

Davies, S., 2017. THE ILLEGAL BUSHMEAT ECOSYSTEM , ZAMBIA. https://doi.org/10.13140/RG.2.2.34946.15040

Davis, F., Davis, F., 1989. Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. MIS Q. 13, 319-. https://doi.org/https://www.researchgate.net/publication/200085965

Davis, F.D., 1989. Perceived Usefulness, Perceived Ease of Use, and User

Acceptance of Information, Source: MIS Quarterly. https://doi.org/https://www.researchgate.net/publication/200085965

Day, M., Gumbo, D., Moombe, K.B., Wijaya, A., Sunderland, T., 2014. Zambia country profile: Monitoring, reporting and verification for REDD+. https://doi.org/10.13140/2.1.2815.7121

De Freitas, B.M.R., 2022. What's driving solar energy adoption in Brazil? Exploring settlement patterns of place and space. Energy Res. Soc. Sci. 89, 102660. https://doi.org/10.1016/j.erss.2022.102660

Derebe, B., Alemu, A., 2023. Non-timber forest product types and its income contribution to rural households in the Horn of Africa: a systematic review. Forest Sci. Technol. 19, 210–220. https://doi.org/10.1080/21580103.2023.2231963

Derebe, B., Alemu, A., Asfaw, Z., 2023. Contribution of Nontimber Forest Products Earn to Livelihood in Rural Households and the Type of Use: A Systematic Review. Int. J. For. Res. https://doi.org/10.1155/2023/9643290

DFID-UKaid, 2020. Demand-Side Subsidies in Off -Grid Solar: A Tool for Achieving Universal Energy.

Diarrassouba, M., Boubacar, I., 2009. Deforestation in Sub- Saharan Africa, in: Boubacar, M.D. and I. (Ed.), Research in Agriculture and Applied Economics. AgEcon Search, Atlanta, Georgia. https://doi.org/https://doi.org/10.22004/AG.ECON.46799

Dillon, D., 2021. Risk Perceptions as Potential Mediators of Environmental Toxicants Associated with Biomass Fuel Use. New Florida J. Anthropol. 1. https://doi.org/10.32473/nfja.v1i2.127163

Dong, L., Mori, A., 2017. Multi-level analysis of sustainable energy transition in Kenya: Role of exogenous actors. Int. J. Energy Econ. Policy 7, 111–122. https://doi.org/https://www.researchgate.net/publication/322094416

Duncan, G., 2016. How Change Happens, First Edition. ed. Oxford University Press, Oxford.

Duraiappah, A., 1999. Poverty and Environmental Degradation:A Literature Review and Analysis.

Durga, N., Schmitter, P., Ringler, C., Mishra, S., Magombeyi, M.S., Ofosu, A., Pavelic, P., Hagos, F., Melaku, D., Verma, S., Minh, T., Matambo, C., 2024. Barriers to the uptake of solar-powered irrigation by smallholder farmers in sub-saharan Africa: A review. Energy Strateg. Rev. 51. https://doi.org/10.1016/j.esr.2024.101294

Egli, F., Orgland, N., Taylor, M., Schmidt, T.S., Steffen, B., 2023. Estimating the cost of capital for solar PV projects using auction results. Energy Policy 183, 113849. https://doi.org/https://doi.org/10.1016/j.enpol.2023.113849

Eiki, N., Sebola, N.A., Sakong, B.M., Mabelebele, M., 2021a. Review on ethnoveterinary practices in sub-saharan africa. Vet. Sci. 8. https://doi.org/10.3390/vetsci8060099

Eiki, N., Sebola, N.A., Sakong, B.M., Mabelebele, M., 2021b. Review on ethnoveterinary practices in sub-saharan africa. Vet. Sci. https://doi.org/10.3390/vetsci8060099

Elmustapha, H., Hoppe, T., Bressers, H., 2018. Understanding stakeholders' views and the influence of the socio-cultural dimension on the adoption of solar energy technology in Lebanon. Sustain. 10. https://doi.org/10.3390/su10020364

ERB, 2024. 2024 MID YEAR STATISTICAL BULLETIN.

ERB Report, 2023. ERB Report. ERB Mid Year Stat. Bullletin.

Estifanos, T.K., Fisher, B., Galford, G.L., Ricketts, T.H., 2024. Impacts of Deforestation on Childhood Malaria Depend on Wealth and Vector Biology. GeoHealth 8. https://doi.org/10.1029/2022GH000764

Ezeh, M. C. and Fidel-Anekwe, T. H. and Ikpabi, P.B., 2023. Evaluating the Potential of Renewable Energy to Address Energy Accessibility, Affordability, and Sustainability Challenges in Africa., in: SPE Nigeria Annual International Conference and Exhibition. pp. 1–14. https://doi.org/10.2118/217214-MS.URL

Fandohan, A.B., Chadare, F.J., Gouwakinnou, G.N., Tovissode, C.F., Bonou, A., Djonlonkou, S.F.B., Houndelo, L.F.H., Sinsin, C.L.B., Assogbadjo, A.E., 2017. Usages traditionnels et valeur économique de Synsepalum dulcificum au Sud-Bénin. Bois Forets des Trop. 17–30. https://doi.org/10.19182/bft2017.332.a31330

FAO-FRA, 2025. Global Forest Resources Assessment - FRA 2025 - Terms and Definitions.

Feleke, S., Anteneh, D., Pydi, B., Satish, R., El-Shahat, A., Abdelaziz, A.Y., 2023. Feasibility and Potential Assessment of Solar Resources: A Case Study in North Shewa Zone, Amhara, Ethiopia. Energies 16. https://doi.org/10.3390/en16062681

Feron, S., 2016. Sustainability of off-grid photovoltaic systems for rural electrification in developing countries: A review. Sustain. 8. https://doi.org/10.3390/SU8121326

Forest Trends, 2021. Timber Legality Risk Dashboard: Zambia 6. https://doi.org/https://www.forest-trends.org/wp-content/uploads/2022/01/Zambia-Timber-Legality-Risk-Dashboard-IDAT-Risk.pdf

Foya, Y.R., Mgeni, C.P., Kadigi, R.M.J., Kimaro, M.H., Hassan, S.N., 2023. Do communities understand the impacts of unlawful bushmeat hunting and trade? Insights from villagers bordering Western Nyerere National Park Tanzania. Glob. Ecol. Conserv. 46, e02626. https://doi.org/10.1016/j.gecco.2023.e02626

Fullerton, D.G., Suseno, A., Semple, S., Kalambo, F., Malamba, R., White, S., Jack, S., Calverley, P.M., Gordon, S.B., 2011. Wood smoke exposure, poverty and impaired lung function in Malawian adults. Int. J. Tuberc. Lung Dis. 15, 391–398.

Gabriel, C.A., Kirkwood, J., Walton, S., Rose, E.L., 2016. How do developing country constraints affect renewable energy entrepreneurs? Energy Sustain. Dev. 35, 52–66. https://doi.org/10.1016/J.ESD.2016.09.006

Gausset, Q., 2001. AIDS and cultural practices in Africa: The case of the Tonga (Zambia). Soc. Sci. Med. 52, 509–518. https://doi.org/10.1016/S0277-9536(00)00156-8

Gebremeskel, T., 2023. Environmental Implications of Charcoal Production and Supply to Bonga Town : The Case of Kefa Zone , Southwest Ethiopia 1–22.

Gershman, B., 2016. Witchcraft beliefs and the erosion of social capital: Evidence from Sub-Saharan Africa and beyond. J. Dev. Econ. 120, 182–208. https://doi.org/10.1016/j.jdeveco.2015.11.005

GET.Invest, 2024. Mini-Grids Partnership: State of the Global Mini-grids Market Report 2024.

GFW, 2025. Forest Monitoring Designed for Action [WWW Document]. Glob. For. Watch. https://doi.org/https://www.globalforestwatch.org/

Gilal, F.G., Shah, S.M.M., Adeel, S., Gilal, R.G., Gilal, N.G., 2022. Consumer e-waste disposal behaviour: A systematic review and research agenda. Int. J. Consum. Stud. 46, 1785–1803. https://doi.org/10.1111/ijcs.12767

Gillingham, K.T., Bollinger, B., 2021. Social Learning and Solar Photovoltaic Adoption. Manage. Sci. 67, 7091–7112. https://doi.org/10.1287/mnsc.2020.3840

GOGLA, 2023. Solar Lantern & Solar Home System. https://doi.org/https://old.gogla.org/wp-content/uploads/2024/05/Gogla_Annual-Report2023_DEF-1.pdf?_gl=1*128wh8z*_up*MQ..*_ga*MTQ2MjY1MjA0NC4xNzQ4MTIwNDAx*_ga_S8GXYMMHFK*czE3NDgxMjA0MDEkbzEkZzAkdDE3NDgxMjA0MDEkajAkbDAkaDAkZExPQjMwdnRsWkVPRXYyOWk2MndabEx6c1Y5eVFLUjM4Ymc.*_ga_G63VJ49YLW*czE3NDgxMjA0MDEkbzEkZzAkdDE3NDgxMjA0MDEkajAkbDAkaDA.

Gómez-Hernández, D.F., Domenech, B., Moreira, J., Farrera, N., López-González, A., Ferrer-Martí, L., 2019. Comparative evaluation of rural electrification project plans: A case study in Mexico. Energy Policy 129, 23–33. https://doi.org/10.1016/J.ENPOL.2019.02.004

Gonçalves, F.M.P., Luís, J.C., Tchamba, J.J., Cachissapa, M.J., Chisingui, A.V., 2019. A rapid assessment of hunting and bushmeat trade along the roadside between five Angolan major towns. Nat. Conserv. 37, 151–160. https://doi.org/10.3897/natureconservation.37.37590

Gondwe, E., Bennett, A., Muhonda, P., Rice, E., 2023. Inland fisheries and the four pillars of food security in Sub-Saharan Africa: Assessing current research trends. Aquat. Ecosyst. Heal. Manag. 25, 42–54. https://doi.org/10.14321/aehm.025.03.42

Goulart, F.F., Chappell, M.J., Mertens, F., Soares-Filho, B., 2023. Sparing or expanding? The effects of agricultural yields on farm expansion and deforestation in the tropics. Biodivers. Conserv. 32, 1089–1104. https://doi.org/10.1007/s10531-022-02540-4

Green Climate Fund (GCF), 2020. An assessment of the environmental and social impact of the Project based on Green Climate Fund ’ s Environmental and

Social Screening Checklist indicates that the Project will have only very limited negative impacts on the population and their ecosystems. UN FAO Rep. 1.

Groenewoudt, A.C., Romijn, H.A., Alkemade, F., 2020. From fake solar to full service: An empirical analysis of the solar home systems market in Uganda. Energy Sustain. Dev. 58, 100–111. https://doi.org/10.1016/j.esd.2020.07.004

GRZ-LGA, 2023. Insights into the Governance and Management of Ward Development Committees in Zambia Learning Paper, Trees in a Sub-Saharan Multi-functional Landscape.

GRZ-National Green Growth Strategy, 2024. National Green Growth Strategy 2024-2030.

GRZ MLGRD, 2021. Guidelines on the Establishment, Management and Operation of Ward Development Committees (WDCs), THE REPUBLIC OF ZAMBIA - MINISTRY OF LOCAL GOVERNMENT AND RURAL DEVELOPMENT.

Guedje, N.M., Tchamou, N., Lejoly, J., 2016. Tree response to bark harvest: the case of a medicinal species, *Garcinia lucida*, as source of raw materials for plant-based drug development. J. Appl. Biosci. 99, 9476. https://doi.org/10.4314/jab.v99i1.13

Gumbo, D., Moombe, K., Kabwe, G., Ojanen, M., Ndhlovu, E., Sunderland, T., Kandulu, M., 2013. Dynamics of the charcoal and indigenous timber trade in Zambia: A scoping study in Eastern, Northern and Northwestern provinces, Dynamics of the charcoal and indigenous timber trade in Zambia: A scoping study in Eastern, Northern and Northwestern provinces. https://doi.org/10.17528/cifor/004113

Guo, Q., Abbas, S., AbdulKareem, H.K.K., Shuaibu, M.S., Khudoykulov, K., Saha, T., 2023. Devising strategies for sustainable development in sub-Saharan Africa: The roles of renewable, non-renewable energy, and natural resources. Energy 284, 128713. https://doi.org/https://doi.org/10.1016/j.energy.2023.128713

Hafner, M., Tagliapietra, S., de Strasser, L., 2018. The Challenge of Energy Access in Africa. pp. 1–21. https://doi.org/10.1007/978-3-319-92219-5_1

Hailu, A.D., Kumsa, D.K., 2020. Ethiopia renewable energy potentials and current state. AIMS Energy 9, 1–14. https://doi.org/10.3934/ENERGY.2021001

Hamauswa, S., Mulenga, J., Shula, R.B., Malunga, M.M., 2017. Promoting micro, small and medium enterprises in beekeeping in Zambias Central Province: Making a case for the adoption of business incubation strategy. African J. Agric. Res. 12, 3045–3060. https://doi.org/10.5897/ajar2017.12449

Handavu, F., Chirwa, P.W.C., Syampungani, S., 2019. Forest Policy and Economics Socio-economic factors influencing land-use and land-cover changes in the miombo woodlands of the Copperbelt province in Zambia. For. Policy Econ. 100, 75–94. https://doi.org/10.1016/j.forpol.2018.10.010

Hansen, M.C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S.A., Tyukavina, A., Thau, D., Stehman, S. V., Goetz, S.J., Loveland, T.R., Kommareddy, A., Egorov, A., Chini, L., Justice, C.O., Townshend, J.R.G., 2013.

High-resolution global maps of 21st-century forest cover change. Science (80-.). 342, 850–853. https://doi.org/10.1126/science.1244693

Hansen, U.E., Reinauer, T., Kamau, P., Wamalwa, H.N., 2022. Managing e-waste from off-grid solar systems in Kenya: Do investors have a role to play? Energy Sustain. Dev. 69, 31–40. https://doi.org/10.1016/j.esd.2022.05.010

Hassan, O., Morse, S., Leach, M., 2020. energies The Energy Lock-In E ff ect of Solar Home Systems : A Case Study in Rural Nigeria. Energies.

Hassen, J.H., Abdulkadir, H.K., 2022. Recent developments in the use of activated charcoal in medicine. J. Med. Sci. 91, e647. https://doi.org/10.20883/medical.e647

Herlihy, J.M., Shaikh, A., Mazimba, A., Gagne, N., Grogan, C., Mpamba, C., Sooli, B., Simamvwa, G., Mabeta, C., Shankoti, P., Messersmith, L., Semrau, K., Hamer, D.H., 2013. Local perceptions, cultural beliefs and practices that shape umbilical cord care: A qualitative study in Southern Province, Zambia. PLoS One 8, 1–14. https://doi.org/10.1371/journal.pone.0079191

Herraiz-Cañete, Á., Ribó-Pérez, D., Bastida-Molina, P., Gómez-Navarro, T., 2022. Forecasting energy demand in isolated rural communities: A comparison between deterministic and stochastic approaches. Energy Sustain. Dev. 66, 101–116. https://doi.org/10.1016/j.esd.2021.11.007

Hicks, J., Ison, N., 2018. An exploration of the boundaries of 'community'' in community renewable energy projects: Navigating between motivations and context.' Energy Policy 113, 523–534. https://doi.org/10.1016/J.ENPOL.2017.10.031

Hlongwane, Z.T., Slotow, R., Munyai, T.C., 2021a. The role of edible insects in rural livelihoods, and identified challenges in Vhembe district, Limpopo, South Africa. Resources 10. https://doi.org/10.3390/resources10120123

Hlongwane, Z.T., Slotow, R., Munyai, T.C., 2021b. Indigenous knowledge about consumption of edible insects in South Africa. Insects 12, 1–19. https://doi.org/10.3390/insects12010022

Hoffman, S.M., Fudge, S., Pawlisch, L., High-Pippert, A., Peters, M., Haskard, J., 2013. Public values and community energy: Lessons from the US and UK. Sustain. 5, 1747–1763. https://doi.org/10.3390/su5041747

Hoffman, S.M., High-Pippert, A., 2005. Community energy: A social architecture for an alternative energy future. Bull. Sci. Technol. Soc. 25, 387–401. https://doi.org/10.1177/0270467605278880

Hoicka, C.E., Savic, K., Campney, A., 2021. Reconciliation through renewable energy? A survey of Indigenous communities, involvement, and peoples in Canada. Energy Res. Soc. Sci. 74, 101897. https://doi.org/10.1016/J.ERSS.2020.101897

Holden, S.T., 1997. Adjustment policies, peasant household resource allocation and deforestation in Northern Zambia: An overview and some policy conclusions. Forum Dev. Stud. 24, 117–134. https://doi.org/10.1080/08039410.1997.9666052

Hudson, A., Milliken, W., Timberlake, J., Giovannini, P., Fijamo, V., Massunde, J., Chipanga, H., Nivunga, M., Ulian, T., 2020. Natural Plant Resources for Sustainable Development: Insights from Community Use in the Chimanimani Trans-Frontier Conservation Area, Mozambique. Hum. Ecol. 48, 55–67. https://doi.org/10.1007/s10745-020-00132-w

Ibe, K.K., Kollur, S.P., 2024. Challenges towards the adoption and use of sustainable cooking methods: a comprehensive review. Sustain. Environ. 10. https://doi.org/10.1080/27658511.2024.2362509

Ibraimo, M., Robinson, J., Annegarn, H.J., 2017. Household energy use and emission. WIT Trans. Ecol. Environ. 211, 161–170. https://doi.org/10.2495/AIR170161

Ickowitz, A., Bwembelo, L., Mulani2, A., Siamutondo2, A.L.M., Banda2, P., Gumbo2, D., Moombe2, K., Steel3, and E.A., 2021. Collection and consumption of wild forest fruits in rural Zambia. Collect. Consum. wild For. fruits Rural Zambia 1–8. https://doi.org/10.17528/cifor/008086

Ickowitz1, A., Bwembelo, L., Mulani, A., Siamutondo, A.L.M., Banda, P., Gumbo, D., Moombe, K., Steel, and E.A., 2021. Collection and consumption of wild forest fruits in rural Zambia, Collection and consumption of wild forest fruits in rural Zambia. Center for International Forestry Research (CIFOR). https://doi.org/10.17528/cifor/008086

Idowu, O.S., De Azevedo, L.B., Zohoori, F.V., Kanmodi, K., Pak, T., 2023. Health risks associated with the production and usage of charcoal: A systematic review. BMJ Open 13. https://doi.org/10.1136/bmjopen-2022-065914

IEA, 2025. IEA-Africa [WWW Document]. https://doi.org/https://www.iea.org/regions/africa

IEA, 2024. Clean Energy Transitions Programme (Annual Report 2024). Int. Energy Agency 119. https://doi.org/https://iea.blob.core.windows.net/assets/d41d8925-4a85-4b1f-9d59-80d9c871d675/CETPAnnualReport2024.pdf

IEA, 2021. World Energy Outlook 2021 - revised version October 2021.

Ihalainen, M., Schure, J., Sola, P., 2020. Where are the women? A review and conceptual framework for addressing gender equity in charcoal value chains in Sub-Saharan Africa. Energy Sustain. Dev. 55, 1–12. https://doi.org/10.1016/j.esd.2019.11.003

Ikejemba, E.C.X., Schuur, P.C., 2020. The empirical failures of attaining the societal benefits of renewable energy development projects in Sub-Saharan Africa. Renew. Energy 162, 1490–1498. https://doi.org/10.1016/J.RENENE.2020.08.052

Ikejemba, E.C.X., Schuur, P.C., Van Hillegersberg, J., Mpuan, P.B., 2017. Failures & generic recommendations towards the sustainable management of renewable energy projects in Sub-Saharan Africa (Part 2 of 2). Renew. Energy 113, 639–647. https://doi.org/10.1016/J.RENENE.2017.06.002

IPCC, 2019. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. https://doi.org/https://www.researchgate.net/publication/345842628

IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Inst. Glob. Environ. Strateg. 4. https://doi.org/https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

Iqbal, M.A., Kim, K.H., 2016. Sampling, pretreatment, and analysis of particulate matter and trace metals emitted through charcoal combustion in cooking activities. TrAC - Trends Anal. Chem. 76, 52–59. https://doi.org/10.1016/j.trac.2015.11.005

Irfan, M., Elavarasan, R.M., Hao, Y., Feng, M., Sailan, D., 2021. An assessment of consumers' willingness to utilize solar energy in China: End-users' perspective. J. Clean. Prod. 292, 126008. https://doi.org/10.1016/j.jclepro.2021.126008

James, J., 2016. A Pro-poor Bias: Leapfrogging and the Context, in: The Impact of Mobile Phones on Poverty and Inequality in Developing Countries. Springer International Publishing, Cham, pp. 33–46. https://doi.org/10.1007/978-3-319-27368-6_4

James, J., 2012. The distributional effects of leapfrogging in mobile phones. Telemat. Informatics 29, 294–301. https://doi.org/10.1016/j.tele.2011.09.001

James, J., 2009. Leapfrogging in mobile telephony: A measure for comparing country performance. Technol. Forecast. Soc. Change 76, 991–998. https://doi.org/10.1016/j.techfore.2008.09.002

Johann, K., Mapila, M., Okello, J., De, S., 2013. Managing Agricultural Commercialization for Inclusive Growth in Sub-Saharan Africa. Glob. Dev. Netw. Sub-Saharan Africa.

Johnson, O.W., Gerber, V., Muhoza, C., 2019. Gender, culture and energy transitions in rural Africa. Energy Res. Soc. Sci. 49, 169–179. https://doi.org/10.1016/j.erss.2018.11.004

Kabisa, M., Mulenga, B.P., Ngoma, H., Kandulu, M.M., 2019. The Role of Policy and Institutions in Greening the Charcoal Value Chain in Zambia 23.

Kachapulula, P.W., Akello, J., Bandyopadhyay, R., Cotty, P.J., 2017. Aflatoxin contamination of groundnut and maize in Zambia: observed and potential concentrations. J. Appl. Microbiol. 122, 1471–1482. https://doi.org/10.1111/jam.13448

Kachapulula, P.W., Bandyopadhyay, R., Cotty, P.J., 2019. Aflatoxin contamination of non-cultivated fruits in Zambia. Front. Microbiol. 10, 1–9. https://doi.org/10.3389/fmicb.2019.01840

Kalaba, F.K., 2016. Barriers to policy implementation and implications for Zambia's forest ecosystems. For. Policy Econ. 69, 40–44. https://doi.org/10.1016/j.forpol.2016.04.004

Kalaba, F.K., Chirwa, P.W., Prozesky, H., Ham, C., 2009. the Role of Indigenous Fruit Trees in Rural Livelihoods: the Case of Communities in the Mwekera Area, Copperbelt Province, Zambia. Acta Hortic. 129–136. https://doi.org/10.17660/actahortic.2009.806.14

Kalinda, T., Bwalya, S., 2014. Utilization of Forest Products and Services for Livelihoods among Households in Zambia. Res. J. Environ. Earth Sci. 6, 102–

111. https://doi.org/10.19026/rjees.6.5748

Kalle Hirvonen, Elia Machado, A.M.S., 2024. This document is discoverable and free to researchers across the globe due to the work of AgEcon Search . Help ensure our sustainability . ａｃｔｏｒｓＩｎｆｌｕｅｎｃｉｎｇＰｒｉｃｅｏｆＡｇｒｉｃｕｌｔｕｒａｌＰｒｏｄｕｃｔｓａｎｄＳｔａｂｉｌｉｔｙＣｏｕｎｔｅ. AgEcon Search 1–26.

Kanyamuna, V., Mulele, S.C., Kanyamuna, C.S., Kanyamuna, L.M., Musanda, P., 2021. The Effect of Information Literacy on Maize Production: Case study of small-scale farmers in Inonge Village, Kazungula District of Zambia. Adv. Soc. Sci. Res. J. 8, 208–229. https://doi.org/10.14738/assrj.88.10719

Kaoma, M., Gheewala, S.H., 2021. Evaluation of the enabling environment for the sustainable development of rural-based bioenergy systems in Zambia. Energy Policy 154, 112337. https://doi.org/10.1016/J.ENPOL.2021.112337

Kaoma, M., Gheewala, S.H., 2020. Assessment of the bioenergy policy for the sustainable development of rural-based bioenergy systems in Zambia. IOP Conf. Ser. Earth Environ. Sci. 463. https://doi.org/10.1088/1755-1315/463/1/012012

Kapembwa, S., Gardiner, A., Pétursson, J.G., 2021. Small-scale fishing: Income, vulnerability and livelihood strategies at Lake Itezhi-Tezhi, Zambia. Dev. South. Afr. 38, 331–352. https://doi.org/10.1080/0376835X.2020.1746636

Kapole, F., Mudenda, S., Jain, P., 2023. Study of major solar energy mini-grid initiatives in Zambia. Results Eng. 18. https://doi.org/10.1016/j.rineng.2023.101095

Kar, S.P.D.S.R.M.D.P.K., 2018. A Review on Activated Charcoal Tooth Paste. Int. J. Sci. Res. 7, 253–254. https://doi.org/10.21275/ART20179278

Kasaro, D., Elijah, P., Imasiku, N., 2019. Deforestation impact on ecosystem services in Kamfinsa sub-catchment of Kafue River Basin in Zambia. J. Ecol. Nat. Environ. 11, 33–45. https://doi.org/10.5897/jene2018.0692

Kassa, G., Teferi, B., Delelegn, N., 2018. The Poverty - Environment Nexus in Developing Countries: Evidence from Ethiopia: A Systematic Review. Asian J. Agric. Extension, Econ. Sociol. 24, 1–13. https://doi.org/10.9734/AJAEES/2018/39310

Kazungu, M., Zhunusova, E., Yang, A.L., Kabwe, G., Gumbo, D.J., Günter, S., 2020. Forest use strategies and their determinants among rural households in the Miombo woodlands of the Copperbelt Province, Zambia. For. Policy Econ. 111, 102078. https://doi.org/10.1016/j.forpol.2019.102078

Keane, J., Kearnes, M., McCloskey, J., Munro, P., Samarakoon, S., 2024. State of Repair in the Off-Grid Solar Sector. Sol. Aid - London 6–21. https://doi.org/https://solar-aid.org/wp-content/uploads/2024/10/State-of-Repair-Off-Grid-Solar-Sector-Oct-2024.-UNSW-SolarAid.pdf

Kelsey, J., 2018. Environmental quality and economic development in Zambia Filling the data gaps, International Growth Centre (IGC). https://doi.org/https://sites.google.com/view/zambiaenvironment/home

Kelvin K. Kishara, Humphreys W. Obulinji, Kennedy. N. Ondimu, 2024. Analysis of the spatial variations in the adoption of solar energy technologies among households in rural and urban areas of Konoin sub-County, Kenya. Open Access Res. J. Sci. Technol. 11, 099-105. https://doi.org/10.53022/oarjst.2024.11.2.0098

Khan, A., Chenggang, Y., Hussain, J., Kui, Z., 2021. Impact of technological innovation, financial development and foreign direct investment on renewable energy, non-renewable energy and the environment in belt & Road Initiative countries. Renew. Energy 171, 479–491. https://doi.org/10.1016/j.renene.2021.02.075

Khan, S., 2023. AGRICULTURE EXPANSION: THE MAIN DRIVER OF FOREST DEGRADATION AND ITS CAUSES. https://doi.org/10.52458/9789388996815.2023.eb.ch-11

Kharas, H., 2007. TRENDS AND ISSUES IN DEVELOPMENT AID. Wolfensohn.

Kinally, C., Antonanzas-Torres, F., Podd, F., Gallego-Schmid, A., 2023. Solar home systems in Malawi: Commercialisation, use and informal waste management. Sustain. Prod. Consum. 42, 367–379. https://doi.org/10.1016/j.spc.2023.10.008

Kirubi, C., 2004. The Impact of Household Energy and Indoor Air Pollution on the Health of the Poor: Implications for Policy Action and Intervention.

Kizilcec, V., Parikh, P., 2020. Solar Home Systems: A comprehensive literature review for Sub-Saharan Africa. Energy Sustain. Dev. 58, 78–89. https://doi.org/10.1016/J.ESD.2020.07.010

Komatsu, S., Kaneko, S., Shrestha, R.M., Ghosh, P.P., 2011. Nonincome factors behind the purchase decisions of solar home systems in rural Bangladesh. Energy Sustain. Dev. 15, 284–292. https://doi.org/10.1016/j.esd.2011.03.003

Korcaj, L., Hahnel, U.J.J., Spada, H., 2015. Intentions to adopt photovoltaic systems depend on homeowners’ expected personal gains and behavior of peers. Renew. Energy 75, 407–415. https://doi.org/10.1016/j.renene.2014.10.007

Kouassi, J.A.K., Kablan, Y.A., Bachmann, M.E., Lemoine, S.R.T., Nielsen, M.R., Koné, I., 2023. Determinants of bushmeat supply sources in rural areas of Côte d’Ivoire. J. Nat. Conserv. 72. https://doi.org/10.1016/j.jnc.2023.126330

Kovacic, Z., Musango, J.K., Buyana, K., Ambole, A., Smit, S., Mwau, B., Ogot, M., Lwasa, S., Brent, A., 2021. Building capacity towards what? Proposing a framework for the analysis of energy transition governance in the context of urban informality in Sub-Saharan Africa. Local Environ. 26, 364–378. https://doi.org/10.1080/13549839.2020.1849075

Kullane, M.A., Abdi-Soojeede, M.I., Farah, A.M., 2022. Impacts of Charcoal Production on Environment and Species Preference in Yaqshid District Mogadishu, Somalia. J. Agric. Ecol. Res. Int. 65–74. https://doi.org/10.9734/jaeri/2022/v23i530238

Kumar, A., 2019. ‘BOMBILE’ [Blast of Mobile Battery in Living Eye] Eye Injury – A Newer Threat to Sight. Delhi J. Ophthalmol. 29, 120–121. https://doi.org/10.7869/djo.465

Kuno, A.K., Begna, N., Mebratu, F., 2023. A feasibility analysis of PV-based off-grid rural electrification for a pastoral settlement in Ethiopia. Energy 282, 128899. https://doi.org/10.1016/j.energy.2023.128899

Kunwar, S.C., Ansari, A.S., Luintel, H., 2009. Non-timber Forest Products Enterprise Development: Regulatory Challenges in the Koshi Hills of Nepal. J. For. Livelihood 8, 39–50. https://doi.org/10.3126/jfl.v8i2.2307

Kurpiers, L.A., Schulte-Herbrüggen, B., Ejotre, I., Reeder, D.A.M., 2015. Bushmeat and emerging infectious diseases: Lessons from Africa, in: Problematic Wildlife: A Cross-Disciplinary Approach. Springer International Publishing, pp. 507–551. https://doi.org/10.1007/978-3-319-22246-2_24

Kutsch, W.L., Merbold, L., Ziegler, W., Mukelabai, M.M., Muchinda, M., Kolle, O., Scholes, R.J., 2011. The charcoal trap: Miombo forests and the energy needs of people. Carbon Balance Manag. 6. https://doi.org/10.1186/1750-0680-6-5

Lawrence, M.G., Williams, S., Nanz, P., Renn, O., 2022. Characteristics, potentials, and challenges of transdisciplinary research. One Earth 5, 44–61. https://doi.org/https://doi.org/10.1016/j.oneear.2021.12.010

Lay, J., Nolte, K., Sipangule, K., 2018. Large-Scale Farms and Smallholders: Evidence from Zambia, in: GIGA (German Institute of Global and Area Studies). https://doi.org/https://www.researchgate.net/publication/323199777

Lazdins, R., Mutule, A., Zalostiba, D., 2021. PV energy communities—challenges and barriers from a consumer perspective: A literature review. Energies 14. https://doi.org/10.3390/en14164873

LCMS, 2022. 2022 Living Conditions Monitoring Survey. Lusaka. https://doi.org/https://www.undp.org/zambia/publications/2022-living-conditions-monitoring-survey-report

Lee, H.S., Jeon, W.S., Kim, Y.K., Purusatama, B.D., Kim, A.R., Cho, J.I., Kim, W.J., Kim, H.C., Kim, N.H., 2019. Design of a modified charcoal production kiln for thermal therapy and evaluation of the charcoal characteristics from this kiln. BioResources 14, 7275–7284. https://doi.org/10.15376/biores.14.3.7275-7284

Lema, R., Bhamidipati, P.L., Gregersen, C., Hansen, U.E., Kirchherr, J., 2021. China's investments in renewable energy in Africa: Creating co-benefits or just cashing-in? World Dev. 141, 105365. https://doi.org/10.1016/J.WORLDDEV.2020.105365

Leonhardt, R., Noble, B., Poelzer, G., Fitzpatrick, P., Belcher, K., Holdmann, G., 2022. Advancing local energy transitions: A global review of government instruments supporting community energy. Energy Res. Soc. Sci. 83, 102350. https://doi.org/10.1016/J.ERSS.2021.102350

Lillo, P., Ferrer-Martí, L., Boni, A., Fernández-Baldor, Á., 2015. Assessing management models for off-grid renewable energy electrification projects using the Human Development approach: Case study in Peru. Energy Sustain. Dev. 25, 17–26. https://doi.org/10.1016/J.ESD.2014.11.003

Lindsey, P.A., Romañach, S.S., Matema, S., Matema, C., Mupamhadzi, I., Muvengwi, J., 2011. Dynamics and underlying causes of illegal bushmeat trade in Zimbabwe. Oryx 45, 84–95. https://doi.org/10.1017/S0030605310001274

Liu, D., Qi, S., Xu, T., 2023. Visual observation or oral communication? The effect of social learning on solar photovoltaic adoption intention in rural China. Energy Res. Soc. Sci. 97, 102950. https://doi.org/10.1016/j.erss.2023.102950

Liu, Y., Bah, Z., 2021. Enabling development impact of solar mini-grids through the community engagement: Evidence from rural Sierra Leone. Energy Policy 154, 112294. https://doi.org/10.1016/j.enpol.2021.112294

Lombardi, F., Balderrama, S., Quoilin, S., Colombo, E., 2019. Generating high-resolution multi-energy load profiles for remote areas with an open-source stochastic model. Energy 177, 433–444. https://doi.org/10.1016/J.ENERGY.2019.04.097

Lowore, J., 2020. Understanding the Livelihood Implications of Reliable Honey Trade in the Miombo Woodlands in Zambia. Front. For. Glob. Chang. 3, 1–16. https://doi.org/10.3389/ffgc.2020.00028

Lyambai, M., 2017. Life Cycle Assessment On Economic Feedbacks In The Charcoal Value Chain In Lusaka District, Zambia. Pan African Univ. 2016–2017.

Mabeta, J., Mweemba, B., Mwitwa, J., 2018. Key drivers of biodiversity loss in Zambia.

Maka, A.O.M., Alabid, J.M., 2022. Solar energy technology and its roles in sustainable development. Clean Energy 6, 476–483. https://doi.org/10.1093/ce/zkac023

Makai, L., Chowdhury, S.P., 2017. Energy solution of Zambia from micro hybric biomass - Solar photovoltaic power plants. 2017 IEEE AFRICON Sci. Technol. Innov. Africa, AFRICON 2017 1266–1271. https://doi.org/10.1109/AFRCON.2017.8095664

Makai, L., Molinas, M., 2013. Biogas - An alternative household cooking technique for Zambia. Proc. 3rd IEEE Glob. Humanit. Technol. Conf. GHTC 2013 17–22. https://doi.org/10.1109/GHTC.2013.6713647

Makai, L., Popoola, O., 2024. Assessment and selection of a micro-hybrid renewable energy system for sustainable energy generation in rural areas of Zambia. Renew. Energy 232. https://doi.org/10.1016/j.renene.2024.121036

Makhado, R., Potgieter, M., Timberlake, J., Gumbo, D., 2014. A review of the significance of mopane products to rural people’s livelihoods in southern Africa. Trans. R. Soc. South Africa 69, 117–122. https://doi.org/10.1080/0035919x.2014.922512

Malange, R., Ayeleso, A., Raji, A.K., 2021. Hybrid Renewable Energy System potentials in rural areas: A case of Zambia. SSRN Electron. J. 1–6. https://doi.org/10.2139/ssrn.3900351

Manda, J., Alene, A.D., Gardebroek, C., Kassie, M., Tembo, G., 2016. Adoption and Impacts of Sustainable Agricultural Practices on Maize Yields and Incomes: Evidence from Rural Zambia. J. Agric. Econ. 67, 130–153. https://doi.org/10.1111/1477-9552.12127

Manda, S., Mukanda, N., 2023. Can REDD+ projects deliver livelihood benefits in private tenure arrangements? Experiences from rural Zambia. For. Policy Econ. 150, 102952. https://doi.org/10.1016/j.forpol.2023.102952

Mandelli, S., Barbieri, J., Mereu, R., Colombo, E., 2016. Off-grid systems for rural electrification in developing countries: Definitions, classification and a comprehensive literature review. Renew. Sustain. Energy Rev. 58, 1621–1646. https://doi.org/10.1016/J.RSER.2015.12.338

Maphosa, V., Maphosa, M., 2020. E-waste management in Sub-Saharan Africa: A systematic literature review, in: Cogent Business & Management. https://doi.org/10.1080/23311975.2020.1814503

Marinda, P.A., Chalula, F., Khayeka-Wandabwa, C., Audain, K., Thilsted, S.H., 2023. Dietary diversity and nutritional status of children aged 6–59 months from rural fishing and non-fishing communities in Zambia. Sci. African 19. https://doi.org/10.1016/j.sciaf.2022.e01527

Martinot, E., Chaurey, A., Lew, D., Moreira, J.R., Wamukonya, N., 2002. Renewable energy markets in developing countries. Annu. Rev. Energy Environ. 27, 309–348. https://doi.org/10.1146/ANNUREV.ENERGY.27.122001.083444

Masikati, P., Sisito, G., Chipatela, F., Tembo, H., Winowiecki, L.A., 2021. Agriculture extensification and associated socio-ecological trade-offs in smallholder farming systems of Zambia. Int. J. Agric. Sustain. 19, 497–508. https://doi.org/10.1080/14735903.2021.1907108

Matenga, C.R., 2017. Outgrowers and livelihoods: The case of Magobbo smallholder block farming in Mazabuka district in Zambia. J. South. Afr. Stud. 43, 551–566. https://doi.org/10.1080/03057070.2016.1211402

Matenga, C.R., Hichaambwa, M., 2017. Impacts of land and agricultural commercialisation on local livelihoods in Zambia: evidence from three models. J. Peasant Stud. 44, 574–593. https://doi.org/10.1080/03066150.2016.1276449

Mathew, A., Adu, K., Diawuo, F., 2023. Renewable Energy Communities in Africa: A Case Study of Five Selected Countries. pp. 52–64. https://doi.org/10.1007/978-3-031-36007-7_4

Mavesere, F., Dzawanda, B., 2023. Effectiveness of Pfumvudza as a resilient strategy against drought impacts in rural communities of Zimbabwe. GeoJournal 88, 3455–3470. https://doi.org/10.1007/s10708-022-10812-3

McCord, R., Parsons, S., Bittner, A.S., Jumbe, C.B.L., Kabwe, G., Pedit, J., Serenje, N., Grieshop, A.P., Jagger, P., 2024. Carbon Monoxide Exposure and Risk of Cognitive Impairment among Cooks in Africa. Indoor Air 2024. https://doi.org/10.1155/2024/7363613

Mclain, R., Lawry, S., 2015. Good governance: A key element of sustainable nontimber forest product harvesting systems.

Meke, G.S., Mumba, R.F.E., Bwanali, R.J., Williams, V.L., 2017. The trade and marketing of traditional medicines in southern and central Malawi. Int. J. Sustain. Dev. World Ecol. 24, 73–87. https://doi.org/10.1080/13504509.2016.1171261

Mekonnen, A., Hassen, S., Jaime, M., Toman, M., Zhang, X.B., 2023. The effect of information and subsidy on adoption of solar lanterns: An application of the BDM bidding mechanism in rural Ethiopia. Energy Econ. 124, 106869. https://doi.org/10.1016/j.eneco.2023.106869

Mencarelli, A., Greco, R., Balzan, S., Grigolato, S., Cavalli, R., 2023. Charcoal-based products combustion: Emission profiles, health exposure, and mitigation strategies. Environ. Adv. 13, 100420. https://doi.org/10.1016/j.envadv.2023.100420

Mercy, N.A., Monah, N.L., Mathias, M.A., 2017. Survey of Wild Vegetables in the Lebialem Highlands of South Western Cameroon. J. Plant Sci. 4, 172. https://doi.org/10.11648/j.jps.20160406.16

Mfune, O., Boon, E.K., 2008. Promoting Renewable Energy Technologies for Rural Development in Africa: Experiences of Zambia. J. Hum. Ecol. 24, 175–189. https://doi.org/10.1080/09709274.2008.11906112

Mickels-Kokwe, G., 2006. Small-scale woodland-based enterprises with outstanding economic potential The case of honey in Zambia.

Middelberg, S.L., 2017. Value chain financing: Evidence from Zambia on smallholder access to finance for mechanization. Enterp. Dev. Microfinance 28, 112–129. https://doi.org/10.3362/1755-1986.16-00027

Miller, E., Buys, L., 2008. The impact of social capital on residential water-affecting behaviors in a drought-prone Australian community. Soc. Nat. Resour. 21, 244–257. https://doi.org/10.1080/08941920701818258

Ministry of Green Economy and Environment (MGEE), 2025. Ministry of Green Economy and Environment, Zambia - Climate [WWW Document]. Minist. Green Econ. Environ. URL https://www.mgee.gov.zm/ (accessed 2.11.25).

Ministry of Information, 2024. Statement by Permanent Secretary- Zambai Ministry of Information and Media on the detection of aflatoxin levels in animal feeds, maize grain and mealie meal in zambia. Lusaka.

Ministry of Small and Medium Enterprise Development (Minister), 2024. Increase in fake solar products worries Zambian Government. [WWW Document]. Zambia News Inf. Serv. URL https://zanis.gov.zm/index.php/2024/10/12/increase-in-fake-solar-products- worries-govt/ (accessed 11.6.24).

Mlambo, A., Maphosa, M., 2017. Miombo Woodland Mushrooms of Commercial Food Value: A Survey of Central Districts of Zimbabwe. J. Food Secur. 5, 51–57. https://doi.org/10.12691/jfs-5-2-5

MOE, 2024. Ministry of Energy (MOE) Update on Zambia’s Energy Situation. [WWW Document]. MOE Off. Website Press Release. https://doi.org/https://www.moe.gov.zm/

MOE, 2019. Zambia Seforall Investiment Prospectus: Sustainable Energy for All Initiative.

Mohammed, J., 2020. Challenges in Implementing Biodiversity Policy in Sub-Saharan Africa Region. Am. J. Biol. Environ. Stat. 6, 24. https://doi.org/10.11648/j.ajbes.20200602.12

Mohammed Wazed, S., Hughes, B.R., O'Connor, D., Kaiser Calautit, J., 2018. A review of sustainable solar irrigation systems for Sub-Saharan Africa. Renew. Sustain. Energy Rev. 81, 1206–1225. https://doi.org/10.1016/J.RSER.2017.08.039

Moller, D., 2015. Dilemmas Of Political Correctness. J. Pract. Ethics 4.

Molotsky, A., Handa, S., 2021. The Psychology of Poverty: Evidence from the Field. J. Afr. Econ. 30, 207–224. https://doi.org/10.1093/jae/ejaa010

Mondoloka, A., 2017. Approaches to supporting local and community development: The view from Zambia. United Nations Univ. World Inst. Dev. Econ. Res. https://doi.org/10.35188/UNU-WIDER/2017/265-6

Moner-Girona, M., Solano-Peralta, M., Lazopoulou, M., Ackom, E.K., Vallve, X., Szabó, S., 2018. Electrification of Sub-Saharan Africa through PV/hybrid mini-grids: Reducing the gap between current business models and on-site experience. Renew. Sustain. Energy Rev. 91, 1148–1161. https://doi.org/10.1016/j.rser.2018.04.018

Moner-Girona, M., Szabo, S., Bhattacharyya, S., 2022. Finance Mechanisms and Incentives for Off-Grid Photovoltaic Technologies in the Solar Belt, in: Letcher, T.M. (Ed.), Comprehensive Renewable Energy (Second Edition). Elsevier, Oxford, pp. 82–113. https://doi.org/https://doi.org/10.1016/B978-0-12-819727-1.00124-2

Moombe, K.B., B.M., M., D., G., M., I., J., S., 2020. Woodfuel production and trade in Choma District, Zambia. Woodfuel Prod. trade Choma Dist. Zambia. https://doi.org/10.17528/cifor/007887

Mooney, G., 2009. Dead Aid: Why aid is not working and how there is another way for Africa | By Dambisa Moyo. London: Allen Lane. 2009 ISBN 978-1-846-14006-8. 188 pages. RRP$32.95. Aust. N. Z. J. Public Health 33, 397–398. https://doi.org/10.1111/J.1753-6405.2009.00416.X

Moreira-Dantas, I.R., Söder, M., 2022. Global deforestation revisited: The role of weak institutions. Land use policy 122. https://doi.org/10.1016/j.landusepol.2022.106383

Motta, C.M., Cerciello, R., De Bonis, S., Mazzella, V., Cirino, P., Panzuto, R., Ciaravolo, M., Simoniello, P., Toscanesi, M., Trifuoggi, M., Avallone, B., 2016. Potential toxicity of improperly discarded exhausted photovoltaic cells. Environ. Pollut. 216, 786–792. https://doi.org/https://doi.org/10.1016/j.envpol.2016.06.048

Mubanga, F.C., Bwalya, B., 2020. Environmental discounting behaviour of smallholder farmers in Chibombo District, Central Zambia. Land use policy 95, 104551. https://doi.org/https://doi.org/10.1016/j.landusepol.2020.104551

Mubita, A., Chowa, T., 2021. Factors leading to increase in Imported Substandard Products on the Zambian Markets: A case of Zambia Bureau of Standards. Int. J. Econ. Policy 1, 83–96. https://doi.org/10.47941/ijecop.554

Mudenda, C., Simate, I.N., Chileshe, M., 2023. A comparative assessment of the poverty and food insecurity experience between food entrepreneurs and smallholder farmers in rural Zambia. J. Agribus. Rural Dev. 69, 279–297.

https://doi.org/10.17306/j.jard.2023.01730

Mugendi, K.D., Mireri, C.O., Enevoldsen, M.K., 2024. Towards development of effective policies and regulations for sustainable off-grid solar electronic waste management systems in Kenya. Eng. Reports 6, 1–11. https://doi.org/10.1002/eng2.12805

Mugisha, J., Ratemo, M.A., Bunani Keza, B.C., Kahveci, H., 2021. Assessing the opportunities and challenges facing the development of off-grid solar systems in Eastern Africa: The cases of Kenya, Ethiopia, and Rwanda. Energy Policy 150, 112131. https://doi.org/10.1016/J.ENPOL.2020.112131

Muhoza, C., Johnson, O.W., 2018. Exploring household energy transitions in rural Zambia from the user perspective. Energy Policy 121, 25–34. https://doi.org/10.1016/J.ENPOL.2018.06.005

Mukisa, N., Manitisa, M.S., Nduhuura, P., Tugume, E., Chalwe, C.K., 2022. Solar home systems adoption in Sub-Saharan African countries: Household economic and environmental benefits assessment. Renew. Energy 189, 836–852. https://doi.org/10.1016/j.renene.2022.03.029

Mulenga, B.P., Richardson, R.B., Mapemba, L., Tembo, G., 2011. The Contribution of Non-Timber Forest Products to Rural Household Income in Zambia. Food Security Research Project, Working paper No. 54. Food Secur. Collab. Policy Briefs.

Mulenga, B.P., Richardson, R.B., Mapemba, L.D., Tembo, G., 2014. The Contribution of Non-Timber Forest Products to Rural Household Income in Zambia.

Mulenga, B.P., Richardson, R.B., Tembo, G., 2012. Non-Timber Forest Products and Rural Poverty Alleviation in Zambia.

Mulenga, B.P., Tembo, S.T., Richardson, R.B., 2019. Electricity access and charcoal consumption among urban households in Zambia. Dev. South. Afr. 36, 585–599. https://doi.org/10.1080/0376835X.2018.1517036

Mulenga, D., Siziya, S., 2019. Indoor Air Pollution Related Respiratory Ill Health, a Sequel of Biomass Use. SciMedicine J. 1, 30–37. https://doi.org/10.28991/scimedj-2019-0101-5

Mulenga, E., Kabanshi, A., Mupeta, H., Ndiaye, M., Nyirenda, E., Mulenga, K., 2023. Techno-economic analysis of off-grid PV-Diesel power generation system for rural electrification: A case study of Chilubi district in Zambia. Renew. Energy 203, 601–611. https://doi.org/10.1016/j.renene.2022.12.112

Mungofa, N., Malongane, F., Tabit, F.T., 2018. an Exploration of the Consumption, Cultivation and Trading of Indigenous Leafy Vegetables in Rural Communities in the Greater Tubatse Local Municipality, Limpopo Province, South Africa. J. Consum. Sci.

Munro, Samarakoon, S., Kearnes, M., Paisley, C., 2023a. The right to repairable energy: A political ecology off-grid solar repair in Zambia. Polit. Geogr. 106, 102962. https://doi.org/10.1016/j.polgeo.2023.102962

Munro, Samarakoon, S., Ngwenya, T., Kanyanga, K., Keane, J., McCloskey, J., Mwale, F., 2023b. Off Grid Solar Repair in Africa: From Burden to Opportunity. Sol. Aid - London 8–21. https://doi.org/https://solar-aid.org/wp-content/uploads/2023/10/SolarAid-Whitepaper-Off-grid-solar-repair-in-Zambia-11.10.2023-1_compressed.pdf

Munyeme, G., Jain, P., 1994. Energy Scenario of Zambia: Prostpects and Constraints in the use of Renewable Energy Resources. Renew. Sustain. Energy Rev. 5, 1363–1370.

Murye, A.F., Pelser, A.J., 2018. Commercial Harvesting of Marula (Sclerocarya Birrea) in Swaziland: A Quest for Sustainability, in: Selected Studies in Biodiversity. InTech. https://doi.org/10.5772/intechopen.76606

Mutelo, C., Nyau, V., Choobe, B., Marinda, P., Hachibamba, T., 2022. Indigenous Knowledge on Utilization Aspects of Selected Edible Wild Fruits from Zambia. J. Food Res. 12, 48. https://doi.org/10.5539/jfr.v12n1p48

Muyenga, T.A., Musonda, D., Chigunta, M., Tumelo Akapelwa Muyenga1*, D.M.M.C., 2018. Journal of Preventive and Rehabilitative Medicine Original Paper Ethnobotanical Survey of Medical Plants Used in Treatment of Diabetes in. J. Prev. Rehabil. Med. 1, 39–44. https://doi.org/10.21617/jprm.2018.0101.5

Muzari, W.M., Muzari, W., 2013. Small Scale Fisheries and Fish Farming, Processing and Marketing in Sub-Saharan Africa: Implications for Poverty Alleviation, Food Security and Nutrition, International Journal of Science and Research (IJSR) ISSN.

Muzekenyi, M., Nyika, F., Hoque, M., 2023. A Small-Scale Farming Intervention Plan for Inclusive Economic Development in Rural South Africa. Int. J. Food, Agric. Nat. Resour. 4, 46–52. https://doi.org/10.46676/ij-fanres.v4i2.136

Mwanza, M., Kaoma, M., Bowa, C.K., Çetin, N.S., Ülgen, K., 2017. The potential of solar energy for sustainable water resource development and averting national social burden in rural areas of Zambia. Period. Eng. Nat. Sci. 5, 1–7. https://doi.org/10.21533/pen.v5i1.64

Mwiba, D., 2018. Medicine Killings, Abduction of People with Albinism, Wealth and Prosperity in North Malawi: A Historical Assessment. Proc. African Futur. Conf. 2, 30–49. https://doi.org/10.1002/j.2573-508X.2018.tb00008.x

Mwitwa, J., 2012. DRIVERS OF DEFORESTATION AND POTENTIAL FOR REDD+ INTERVENTIONS IN ZAMBIA. https://doi.org/https://api.semanticscholar.org/CorpusID:210877445

Naamara, W., Muhwezi, W.W., 2014. Factors Associated With Alcohol Dependence Among Adult Male Clients in Butabika Hospital, Uganda. J. Soc. Work Pract. Addict. 14, 322–326. https://doi.org/10.1080/1533256X.2014.936251

Nabaweesi, J., Kabuye, F., Adaramola, M.S., 2024. Households' willingness to adopt solar energy for business use in Uganda. Int. J. Energy Sect. Manag. 18, 26–42. https://doi.org/10.1108/IJESM-08-2022-0001

Nalwamba, D., 2021. The Electronic Waste Management Crisis- A Situation Analysis of Zambia. https://doi.org/10.21203/rs.3.rs-1132285/v1

Nalwamba, D.S., 2022. The Electronic Waste Management Crisis-A Situation

Analysis of Zambia. Res. Sq. 1–12. https://doi.org/10.21203/rs.3.rs-1132285/v1

Nansikombi, H., Fischer, R., Ferrer Velasco, R., Lippe, M., Kalaba, F.K., Kabwe, G., Günter, S., 2020a. Can de facto governance influence deforestation drivers in the Zambian Miombo? For. Policy Econ. 120. https://doi.org/10.1016/j.forpol.2020.102309

Nansikombi, H., Fischer, R., Kabwe, G., Günter, S., 2020b. Exploring patterns of forest governance quality: Insights from forest frontier communities in Zambia´s Miombo ecoregion. Land use policy 99, 104866. https://doi.org/10.1016/j.landusepol.2020.104866

Narjabadifam, N., Fouladvand, J., Gül, M., 2023. Critical Review on Community-Shared Solar—Advantages, Challenges, and Future Directions. Energies 16, 1–25. https://doi.org/10.3390/en16083412

Naumann, M., Rudolph, D., 2020. Conceptualizing rural energy transitions: Energizing rural studies, ruralizing energy research. J. Rural Stud. 73, 97–104. https://doi.org/https://doi.org/10.1016/j.jrurstud.2019.12.011

Ndlovu, I., Nunu, W.N., Mudonhi, N., Dube, O., Maviza, A., 2019. Land use−land cover changes and Mopani worm harvest in Mangwe District in Plumtree, Zimbabwe. Environ. Syst. Res. 8. https://doi.org/10.1186/s40068-019-0141-5

NDN, 2024. Report Only If You Go 3 Days Without ZESCO Power. News Diggers Newsp. 1,6.

Ndubani, P., Höjer, B., 1999. Traditional healers and the treatment of sexually transmitted illnesses in rural Zambia. J. Ethnopharmacol. 67, 15–25. https://doi.org/10.1016/S0378-8741(99)00075-6

Nduka, E., 2021. How to get rural households out of energy poverty in Nigeria: A contingent valuation. Energy Policy 149, 112072. https://doi.org/10.1016/j.enpol.2020.112072

Newell, P., Bulkeley, H., 2017. Landscape for change? International climate policy and energy transitions: evidence from sub-Saharan Africa. Clim. Policy 17, 650–663. https://doi.org/10.1080/14693062.2016.1173003

Ngoma, H., Finn, A., Kabisa, M., 2024. Climate shocks, vulnerability, resilience and livelihoods in rural Zambia. Clim. Dev. 16, 490–501. https://doi.org/10.1080/17565529.2023.2246031

Ngoma, H., Pelletier, J., Mulenga, B.P., Subakanya, M., 2021. Climate-smart agriculture, cropland expansion and deforestation in Zambia: Linkages, processes and drivers. Land use policy 107, 105482. https://doi.org/10.1016/j.landusepol.2021.105482

Ngoma, H., Samboko, P., Nkonde, C., Gumbo, D., 2019. THE VALUE OF NON-TIMBER FOREST PRODUCTS IN ZAMBIA: INDIRECT AND NON-USE BENEFITS. https://doi.org/https://www.researchgate.net/publication/322656117

Ngonda, T., Nkhoma, R., Ngonda, V., 2023. Perceptions of Solar Photovoltaic System Adopters in Sub-Saharan Africa: A Case of Adopters in Ntchisi, Malawi. Energies 16. https://doi.org/10.3390/en16217350

Nixon Opiyo, N., 2019. Neighbourhood Influence and Social Acceptance of PV Systems in Rural Developing Communities 2019, 2006–2012. https://doi.org/10.4229/EUPVSEC20192019-7DV.2.28

Njenga, M., Kirimi, M., Koech, G., Wanjira, E.O., Muriuki, J., Sola, P., Bourne, M., Siko, I., Mendum, R., 2023. Improvements in charcoal production and the environmental implications: Potential for the invasive Prosopis juliflora in Kenya. Resour. Conserv. Recycl. Adv. 19, 200181. https://doi.org/10.1016/j.rcradv.2023.200181

Nolan, J.M., Schultz, P.W., Cialdini, R.B., Goldstein, N.J., Griskevicius, V., 2008. Normative social influence is underdetected. Personal. Soc. Psychol. Bull. 34, 913–923. https://doi.org/10.1177/0146167208316691

Nolte, K., Subakanya, M., 2016. Relationship between Large-Scale Agricultural Investors and Local Communities: Lessons from Two Investments In Zambia. Indaba Agric. Policy Res. Inst. https://doi.org/https://www.researchgate.net/publication/300002300

Norrgren, L., Pettersson, U., Örn, S., Bergqvist, P.A., 2000. Environmental monitoring of the Kafue River, located in the Copperbelt, Zambia. Arch. Environ. Contam. Toxicol. 38, 334–341. https://doi.org/10.1007/s002449910044

Nyarko, I., Nwaogu, C., Miroslav, H., Peseu, P.O., 2021. Socio-Economic Analysis of Wood Charcoal Production as a Significant Output of Forest Bioeconomy in Africa. Forests.

Nygaard, I., Hansen, U.E., Larsen, T.H., 2016. The emerging market for pico-scale solar PV systems in Sub-Saharan Africa: From donor-supported niches toward market-based rural electrification. https://doi.org/https://www.researchgate.net/publication/318108596

Nyirenda, J., Chipuwa, M., 2024. An ethnobotanical study of herbs and medicinal plants used in Western, Copperbelt, Central and Northern provinces of Zambia. Phytomedicine Plus 4, 100514. https://doi.org/10.1016/j.phyplu.2023.100514

Nyoh, I., 2021. Communicating climate change and energy in rural Africa: A case analysis to explain how participatory communication can support transition to renewables and adoption of solar technologies in rural Africa. Ciências e Políticas Públicas / Public Sci. Policies. https://doi.org/10.33167/2184-0644.cpp2021.vviin2/pp.183-200

Obeng-Darko, N.A., 2023. Policy Trends on Renewable Energy for Decentralised Electrification as a Catalyst for Achieving Goal Seven of the Sustainable Development Goals in sub-Saharan Africa. Renew. Energy Law Policy Rev. 8, 12–24. https://doi.org/10.4337/relp.2018.04.02

Ochieng, J., Govindasamy, R., Dinssa, F.F., Afari-Sefa, V., Simon, J.E., 2019. Retailing traditional African vegetables in Zambia. Agric. Econ. Res. Rev. 32, 175. https://doi.org/10.5958/0974-0279.2019.00030.2

Okoye, C.O., Oranekwu-Okoye, B.C., 2018. Economic feasibility of solar PV system for rural electrification in Sub-Sahara Africa. Renew. Sustain. Energy Rev. 82, 2537–2547. https://doi.org/10.1016/j.rser.2017.09.054

Olatomiwa, L., Sadiq, A.A., Longe, O.M., Ambafi, J.G., Jack, K.E., Abd'azeez, T.A., Adeniyi, S., 2022. An Overview of Energy Access Solutions for Rural Healthcare Facilities. Energies 15, 1–23. https://doi.org/10.3390/en15249554

Opiyo, N.N., 2019. Impacts of neighbourhood influence on social acceptance of small solar home systems in rural western Kenya. Energy Res. Soc. Sci. 52, 91–98. https://doi.org/10.1016/j.erss.2019.01.013

Orisakwe, O.E., Frazzoli, C., Ilo, C.E., Oritsemuelebi, B., 2020. Public Health Burden of E-waste in Africa. J. Heal. Pollut. 9, 1–12. https://doi.org/10.5696/2156-9614-9.22.190610

Otiti, T., Soboyejo, W.O., 2006. Limited contribution of photovoltaic energy technology to economic development of sub-Saharan Africa. Perspect. Glob. Dev. Technol. 5, 69–80. https://doi.org/10.1163/156915006777354455

Pahalvi, H.N., Rafiya, L., Rashid, S., Nisar, B., Kamili, A.N., 2021. Chemical Fertilizers and Their Impact on Soil Health, in: Dar, G.H., Bhat, R.A., Mehmood, M.A., Hakeem, K.R. (Eds.), Microbiota and Biofertilizers, Vol 2: Ecofriendly Tools for Reclamation of Degraded Soil Environs. Springer International Publishing, Cham, pp. 1–20. https://doi.org/10.1007/978-3-030-61010-4_1

Paltzer, J., Okafor, C., Chiluba, B., Taylor, K.P., 2021. CROSS-SECTIONAL STUDY OF ALCOHOL PREFERENCES AND EXPENDITURES ON FOOD INSECURITY BETWEEN URBAN AND RURAL SETTINGS IN ZAMBIA. Afr. J. Drug Alcohol Stud. 20, 53–63. https://doi.org/10.4314/ajdas.v20i1.4

Park, C.-Y., Melendez, A.C., 2024. ADB BRIEFS for the Clean Energy Transition. African Dev. Bank Debriefs 6. https://doi.org/https://doi.org/10.22617/brf240251-2

Parkins, J.R., Rollins, C., Anders, S., Comeau, L., 2018. Predicting intention to adopt solar technology in Canada: The role of knowledge, public engagement, and visibility. Energy Policy 114, 114–122. https://doi.org/10.1016/j.enpol.2017.11.050

Patel, S., Khandelwal, A., Leavey, A., Biswas, P., 2016. A model for cost-benefit analysis of cooking fuel alternatives from a rural Indian household perspective. Renew. Sustain. Energy Rev. 56, 291–302. https://doi.org/10.1016/j.rser.2015.11.047

Paul Mmahi, O., Usman, A., 2020. "Hunting Is Our Heritage; We Commit No Offence": Kainji National Park Wildlife Poachers, Kaiama, Kwara State Nigeria. Deviant Behav. 41, 1510–1523. https://doi.org/10.1080/01639625.2019.1629537

Peters, J., Sievert, M., Toman, M.A., 2019. Rural electrification through mini-grids: Challenges ahead. Energy Policy 132, 27–31. https://doi.org/10.1016/J.ENPOL.2019.05.016

Petroli, P.A., Camargo, P.S.S., de Souza, R.A., Veit, H.M., 2024. Assessment of toxicity tests for photovoltaic panels: A review. Curr. Opin. Green Sustain. Chem. 47, 100885. https://doi.org/10.1016/j.cogsc.2024.100885

Phillip, E., Langevin, J., Davis, M., Kumar, N., Walsh, A., Jumbe, V., Clifford, M., Conroy, R., Stanistreet, D., 2023. Improved cookstoves to reduce household air pollution exposure in sub-Saharan Africa: A scoping review of intervention studies, PLoS ONE. https://doi.org/10.1371/journal.pone.0284908

Phiri, D., Chanda, C., Nyirenda, V.R., Lwali, C.A., 2022. An assessment of forest loss and its drivers in protected areas on the Copperbelt province of Zambia: 1972–2016. Geomatics, Nat. Hazards Risk 13, 148–166. https://doi.org/10.1080/19475705.2021.2017021

Phiri, D., Morgenroth, J., Xu, C., 2019. Four decades of land cover and forest connectivity study in Zambia—An object-based image analysis approach. Int. J. Appl. Earth Obs. Geoinf. 79, 97–109. https://doi.org/10.1016/j.jag.2019.03.001

Phiri, D., Mwitwa, J., Ng'andwe, P., Kanja, K., Munyaka, J., Chileshe, F., Hamazakaza, P., Kapembwa, S., Kwenye, J.M., 2023. Agricultural expansion into forest reserves in Zambia: a remote sensing approach. Geocarto Int. 38. https://doi.org/10.1080/10106049.2023.2213203

Pillot, B., Muselli, M., Poggi, P., Dias, J.B., 2019. Historical trends in global energy policy and renewable power system issues in Sub-Saharan Africa: The case of solar PV. Energy Policy 127, 113–124. https://doi.org/10.1016/j.enpol.2018.11.049

Pillot, B., Muselli, M., Poggi, P., Dias, J.B., 2017. On the impact of the global energy policy framework on the development and sustainability of renewable power systems in Sub-Saharan Africa: the case of solar PV 1–25. https://doi.org/https://doi.org/10.48550/arXiv.1704.01480

Pitshou, N., Bokoro., Kyandoghere, K., 2023. The Impact of Market-Based Policies on Access to Electricity and Sustainable Development in Sub-Saharan Africa 5, 1–14. https://doi.org/10.1007/978-3-031-29586-7

Pitso, F.S., Lebese, M.R., 2014. Traditional Uses of Wild Edible Plants in Arid Areas of South Africa. J. Hum. Ecol. 48, 23–31. https://doi.org/10.1080/09709274.2014.11906771

PRO, Z., 2024. POWER SUPPLY UPDATE [WWW Document]. Press Release. https://doi.org/https://www.zesco.co.zm/media_releases.php

Qureshi, T.M., Ullah, K., Arentsen, M.J., 2017. Factors responsible for solar PV adoption at household level: A case of Lahore, Pakistan. Renew. Sustain. Energy Rev. 78, 754–763. https://doi.org/10.1016/j.rser.2017.04.020

Qwabe, Q.N., Pittawaty, T., 2023. Exploring the Role of Indigenous Vegetables in Rural Livelihoods: Perceptions from the Ntuze Community. South African J. Agric. Ext. 51, 142–154. https://doi.org/10.17159/2413-3221/2023/v51n1a14377

Rabetanetiarimanana, J.C.I., Radanielina, M.H., Rakotondramiarana, H.T., Rabetanetiarimanana, J.C.I., Radanielina, M.H., Rakotondramiarana, H.T., 2018. PV-Hybrid Off-Grid and Mini-Grid Systems for Rural Electrification in Sub-Saharan Africa. Smart Grid Renew. Energy 09, 171–185. https://doi.org/10.4236/sgre.2018.910011

Rai, V., Beck, A.L., 2015. Public perceptions and information gaps in solar energy in Texas. Environ. Res. Lett. 10. https://doi.org/10.1088/1748-9326/10/7/074011

Raj, A., Jhariya, M.K., Khan, N., Bargali, S.S., Ghanshyam, Devi, A., 2022. Impact of Deforestation on Faunal Diversity and Its Management Strategies, in: Panwar, P., Shukla, G., Bhat, J.A., Chakravarty, S. (Eds.), Land Degradation Neutrality: Achieving SDG 15 by Forest Management. Springer Nature Singapore, Singapore, pp. 43–60. https://doi.org/10.1007/978-981-19-5478-8_3

Ratnasingam, J., Ng'Andwe, P., Ioras, F., Abrudan, I. V., 2014. Forestry and Forest Products Industries in Zambia and the Role of REDD+ Initiatives. Int. For. Rev. 16, 474–484. https://doi.org/10.1505/146554814813484068

Rehman, I.H., Kar, A., Banerjee, M., Kumar, P., Shardul, M., Mohanty, J., Hossain, I., 2012. Understanding the political economy and key drivers of energy access in addressing national energy access priorities and policies. Energy Policy 47, 27–37. https://doi.org/10.1016/j.enpol.2012.03.043

REN21, 2020. Key Findings of the GSR. Renewables 2020 Glob. Status Rep. 36.

Rich, E.P., Nkosi, S., Morojele, N.K., 2015. Masculinities, alcohol consumption, and sexual risk behavior among male tavern attendees: A qualitative study in North West Province, South Africa. Psychol. Men Masculinity 16, 382–392. https://doi.org/10.1037/a0038871

Richardson, R.B., Olabisi, L.S., Waldman, K.B., Sakana, N., Brugnone, N.G., 2021. Modeling interventions to reduce deforestation in Zambia. Agric. Syst. 194, 103263. https://doi.org/10.1016/j.agsy.2021.103263

Ricketts, K., Shackleton, C.M., 2020. Integrating livelihoods and forest conservation through beekeeping in northern KwaZulu-Natal. Dev. South. Afr. 37, 661–677. https://doi.org/10.1080/0376835X.2019.1698408

Ripple, W.J., Abernethy, K., Betts, M.G., Chapron, G., Dirzo, R., Galetti, M., Levi, T., Lindsey, P.A., Macdonald, D.W., Machovina, B., Newsome, T.M., Peres, C.A., Wallach, A.D., Wolf, C., 2016. Bushmeat hunting and extinction risk to the world's mammals. R. Soc. Open Sci. 3. https://doi.org/10.1098/rsos.160498

Ritchie, H., 2021. Global deforestation peaked in the 1980s. Can we bring it to an end? Our World Data 6. https://doi.org/https://ourworldindata.org/global-deforestation-peak

Rogers, E., 2003a. Diffusion of Innovation, 5th ed. Free Press.

Rogers, E., 2003b. RUDSHAM (PS) 5 Rogers 2003 Diffusion of Innovation, 5th ed. Free Press. https://doi.org/https://ebookcentral.proquest.com/lib/reading/detail.action?docID=4935198.

Rogerson, C.M., 2019. African traditional beer: changing organization and spaces of South Africa's sorghum beer industry. African Geogr. Rev. 38, 253–267. https://doi.org/10.1080/19376812.2019.1589735

Rookmaaker, L.C., 2020. Culture in Africa, Bibliography of the Rhinoceros. https://doi.org/10.1201/9781003079057-13

Roomaney, Wright, C.Y., Cairncross, E., Abdelatif, N., Cois, A., Turawa, E.B., Awotiwon, O.F., Neethling, I., Nojilana, B., Pacella, R., Bradshaw, D., Wyk, V.P., 2022. Estimating the changing burden of disease attributable to interpersonal violence in South Africa for 2000, 2006 and 2012. South African Med. J. 112, 693–704. https://doi.org/10.7196/SAMJ.2022.v112i8b.16512

Rose, J., Bensch, G., Munyehirwe, A., Peters, J., 2022. The forgotten coal: Charcoal demand in sub-Saharan Africa. World Dev. Perspect. 25. https://doi.org/10.1016/j.wdp.2022.100401

Sachs, J., 2008. The end of poverty: Economic possibilities for our time. Eur. J. Dent. Educ. 12, 17–21. https://doi.org/10.1111/j.1600-0579.2007.00476.x

Sadik-Zada, E.R., Loewenstein, W., Dumbuya, F.S., 2023. Modernization through solar off-grid electrification? A mixed picture for rural Sierra Leone. Electr. J. 36, 107316. https://doi.org/10.1016/j.tej.2023.107316

Sakala, D., Olin, S., Santos, M.J., 2023. The effect of charcoal production on carbon cycling in African biomes. GCB Bioenergy 15, 593–612. https://doi.org/10.1111/gcbb.13037

Sakala, M., 2016. WILDLIFE RESOURCE UTILISATION AND RURAL LIVELIHOODS IN MUKUNGULE GAME MANAGEMENT AREA, MPIKA, ZAMBIA.

Sakala, W.D., Moyo, S., 2017. Socio-Economic Benefits of Community Participation in Wildlife Management in Zambia. Sustain. Resour. Manag. J. 1–18. https://doi.org/10.5281/zenodo

Samarakoon, S., Bartlett, A., Munro, P., 2021. Somewhat original: energy ethics in Malawi’s off-grid solar market. Environ. Sociol. 7, 164–175. https://doi.org/10.1080/23251042.2021.1893428

Samarakoon, S., Munro, P., Zalengera, C., Kearnes, M., 2022. The afterlives of off-grid solar: The dynamics of repair and e-waste in Malawi. Environ. Innov. Soc. Transitions 42, 317–330. https://doi.org/https://doi.org/10.1016/j.eist.2022.01.009

Samboko, P.C., Moombe, K., Syampungani, S., 2016. Load shedding and charcoal use in Zambia: What are the implications on forest resources The political economy of indigenous timber production and trade in Zambia View project.

Sanou, B., 2020. 28. Witchcraft Accusations: A Challenge for Families, Communities, and Churches in Africa. OKH J. Anthropol. Ethnogr. Anal. Through Eyes Christ. Faith 4, 145–148. https://doi.org/10.18251/okh.v4i1.79

Santos, M., Ferreira, A., Lanzinha, J., 2023. Overview of Energy Systems in Africa: A Comprehensive Review. Solar 3, 638–649. https://doi.org/10.3390/solar3040034

Santos, M.M., Vaz Ferreira, A.T., Lanzinha, J.C.G., 2023. Overview of Energy Systems in Africa: A Comprehensive Review. Solar 3, 638–649. https://doi.org/10.3390/solar3040034

Sawadogo-Lingani, H., Owusu-Kwarteng, J., Glover, R., Diawara, B., Jakobsen, M., Jespersen, L., 2021. Sustainable Production of African Traditional Beers With Focus on Dolo, a West African Sorghum-Based Alcoholic Beverage. Front. Sustain. Food Syst. https://doi.org/10.3389/fsufs.2021.672410

Schmitter, P., Kibret, K.S., Lefore, N., Barron, J., 2018. Suitability mapping framework for solar photovoltaic pumps for smallholder farmers in sub-Saharan Africa. Appl. Geogr. 94, 41–57. https://doi.org/10.1016/j.apgeog.2018.02.008

Schulte, E., Scheller, F., Sloot, D., Bruckner, T., 2022. A meta-analysis of residential PV adoption: the important role of perceived benefits, intentions and antecedents in solar energy acceptance. Energy Res. Soc. Sci. 84, 102339. https://doi.org/10.1016/j.erss.2021.102339

Sedano, F., Mizu-Siampale, A., Duncanson, L., Liang, M., 2022. Influence of Charcoal Production on Forest Degradation in Zambia: A Remote Sensing Perspective. Remote Sens. 14. https://doi.org/10.3390/rs14143352

Sekonya, J.G., McClure, N.J., Wynberg, R.P., 2020. New pressures, old foodways: Governance and access to edible mopane caterpillars, imbrasia (=gonimbrasia) Belina, in the context of commercialization and environmental change in South Africa. Int. J. Commons 14, 139–153. https://doi.org/10.5334/ijc.978

Senya, B.K., Anim, N.B., Domson, B.S.K., Adu, P., 2018. Prevalence of Asymptomatic Mycobacterium tuberculosis Infection in Charcoal Producers: A Cross-Sectional Study in Kaase, Ghana . J. Pathog. 2018, 1–4. https://doi.org/10.1155/2018/9094803

Serenje, N., Price, M., Njobvu, C., 2022. MECS eCook Zambia National Policy and Markets Review. Mod. Energy Cook. Serv.

Sesan, T., 2012. Navigating the limitations of energy poverty: Lessons from the promotion of improved cooking technologies in Kenya. Energy Policy 47, 202–210. https://doi.org/10.1016/j.enpol.2012.04.058

Shackleton, C., 2015. Ecological sustainability for non-timber forest products: dynamics and case-studies of harvesting.

Shackleton, C., Shackleton, S., 2014. The importance of non-timber forest products in rural livelihood security and as safety nets: A review of evidence from South Africa.

Shackleton, C.M., Garekae, H., Sardeshpande, M., Sinasson Sanni, G., Twine, W.C., 2024. Non-timber forest products as poverty traps: Fact or fiction? For. Policy Econ. https://doi.org/10.1016/j.forpol.2023.103114

Shakeel, S.R., Juntunen, J.K., Rajala, A., 2024. Business models for enhanced solar photovoltaic (PV) adoption: Transforming customer interaction and engagement practices. Sol. Energy 268, 112324. https://doi.org/10.1016/j.solener.2024.112324

Shakeel, S.R., Rajala, A., 2020. Factors Influencing Households' Intention to Adopt Solar PV: A Systematic Review. Adv. Intell. Syst. Comput. 1209 AISC, 282–289. https://doi.org/10.1007/978-3-030-50791-6_36

Shang, J., Wu, H., Zhou, S., Zhong, J., Feng, Y., Qiang, B., 2018. IMPC: Influence maximization based on multi-neighbor potential in community networks. Phys. A Stat. Mech. its Appl. 512, 1085–1103. https://doi.org/10.1016/j.physa.2018.08.045

Sharon Handongwe, 2017. Ending Poverty Through Ubuntu. J. Psychol. Res. 7, 592–603. https://doi.org/10.17265/2159-5542/2017.11.002

Shen, D.Y., Ferguson-Gow, H., Groner, V., Munyai, T.C., Slotow, R., Pearson, R.G., 2023. Potential decline in the distribution and food provisioning services of the mopane worm (Gonimbrasia belina) in southern Africa. Front. Biogeogr. 15. https://doi.org/10.21425/F5FBG59408

Sher, H., Aldosari, A., Ali, A., de Boer, H.J., 2014. Economic benefits of high value medicinal plants to Pakistani communities: An analysis of current practice and potential. J. Ethnobiol. Ethnomed. 10. https://doi.org/10.1186/1746-4269-10-71

Shokrgozar, S., Remme, D., Stock, R., 2024. "We Have to Convince Them Whatever it Takes:" The Climate Necropolitics of Energy Transitions in India and Zambia. Geoforum 153, 103945. https://doi.org/https://doi.org/10.1016/j.geoforum.2024.103945

Shrestha, S.L., 2022. Burden of Respiratory Diseases Attributable to Household Air Pollution in Nepal: National and Provincial Estimates. Nepal. J. Stat. 6, 15–28. https://doi.org/10.3126/njs.v6i01.50799

Siachisa, M., Shula, R., Mulima, S.S., Rabson Nguluwe, P., 2023. Examining the Effectiveness of Ward Development Committees in the Implementation of the Decentralisation Policy in Zambia: A Case of Chibombo District (2016-2021). Int. J. Humanit. Soc. Sci. Educ. 10, 34–47. https://doi.org/10.20431/2349-0381.1002004

Siakachoma, K., 2019. GENDER ROLES AND THEIR IMPLICATIONS IN CHARCOAL PRODUCTION AND MARKETING IN MAKUNKA AREA OF KAZUNGULA DISTRICT, ZAMBIA. Univ. Zambia. University of Zambia.

Sidney, M., Chileshe, M., Adwell, L., Violet, M., Wamwita, S., Maud, K., Jere, M., Ilya, K., 2024. Supra-additivity, antagonism and antibacterial activity of Cassia abbreviata, Combretum hereroense Schinz and Acacia polyacantha: An alternative therapeutic approach against Neisseria Gonorrhoea infections. J. Pharmacogn. Phytochem. 13, 203–208. https://doi.org/10.22271/phyto.2024.v13.i4c.15011

Sileshi, G.W., Tibuhwa, D.D., Mlambo, A., 2023. Underutilized wild edible fungi and their undervalued ecosystem services in Africa. CABI Agric. Biosci. 4, 1–20. https://doi.org/10.1186/s43170-023-00145-7

Silva, J.A., Sedano, F., Flanagan, S., Ombe, Z.A., Machoco, R., Meque, C.H., Sitoe, A., Ribeiro, N., Anderson, K., Baule, S., Hurtt, G., 2019. Charcoal-related forest degradation dynamics in dry African woodlands: Evidence from Mozambique. Appl. Geogr. 107, 72–81. https://doi.org/10.1016/j.apgeog.2019.04.006

Simbeye, T., Mweene, D., Chimwala-Selico, C., Chisanga, A., Ibrahim, A., Mandona, E., Mwansa, P., Chimwala, M., Mbangweta, I., Nyahodah, I., Phiri, B., Chakolwa, G., Munsanje, M., 2024. Epidemiology of Sexually Transmitted Infections Among Sexually Active Individuals in Monze District, Zambia. World J. Public Heal. 9, 243–254. https://doi.org/10.11648/j.wjph.20240903.12

Simkovich, S.M., Goodman, D., Roa, C., Crocker, M.E., Gianella, G.E., Kirenga, B.J., Wise, R.A., Checkley, W., 2019. The health and social implications of household air pollution and respiratory diseases. npj Prim. Care Respir. Med. 29, 1–17. https://doi.org/10.1038/s41533-019-0126-x

Singh, R., 2018. The hidden dangers of chemical fertilizers. Occup. Heal. Saf. 6, 1–5. https://doi.org/10.36948/ijfmr.2024.v06i03.23134

Sinvula, R., Abo-Al-Ez, K.M., Kahn, M.T., 2021. Maintenance and Disposal of the solar panels. Int. Conf. Electr. Comput. Energy Technol. ICECET 2021 1–6. https://doi.org/10.1109/ICECET52533.2021.9698627

Soboyejo, Otiti, 2006. Limited Contribution of Photovoltaic Energy Technology to Economic Development of Sub-Saharan Africa. Perspect. Glob. Dev. Technol. 5, 69–80. https://doi.org/10.1163/156915006777354455

Sovacool, B.K.., Drupady, I.M., 2016. Energy access, poverty, and development : the governance of small-scale renewable energy in developing Asia. Routledge.

Sovacool, B.K., 2013. Expanding renewable energy access with pro-poor public private partnerships in the developing world. Energy Strateg. Rev. 1, 181–192. https://doi.org/10.1016/j.esr.2012.11.003

Sovacool, B.K., Griffiths, S., 2020. The cultural barriers to a low-carbon future: A review of six mobility and energy transitions across 28 countries. Renew. Sustain. Energy Rev. 119, 109569. https://doi.org/10.1016/j.rser.2019.109569

Ssekibaala, S.D., Kasule, T.A., 2023. Examination of the poverty-environmental degradation nexus in Sub-Saharan Africa. Reg. Sustain. 4, 296–308. https://doi.org/https://doi.org/10.1016/j.regsus.2023.08.007

State of Global Air, 2024. State of Global Air (SOGA) 2024 Report in partnership with UNICEF.

Steel, E.A., Bwembelo, L., Mulani, A., Siamutondo, A.L.M., Banda, P., Gumbo, D., Moombe, K., Ickowitz, A., 2022. Wild foods from forests: Quantities collected across Zambia. People Nat. 4, 1159–1175. https://doi.org/10.1002/pan3.10367

Steyn, R., 2022. Socio-cultural Status of Albinism in Africa: Challenging Myths, Concepts, and Stereotypes. J. Glob. Aware. 3, 1–18. https://doi.org/10.24073/jga/3/02/03

Stone, G., 2024. North Swaka Project 2023 Impact Summary. Mkushi Zambia.

Stone, M.T., Stone, L.S., 2022. Community-Based ecotourism and bushmeat consumption dynamics: Implications for conservation and community development. J. Sustain. Tour. 30, 2549–2573. https://doi.org/10.1080/09669582.2020.1845708

Stritzke, S., 2018. ‘Clean energy for all’: the implementation of Scaling Solar in Zambia. World J. Sci. Technol. Sustain. Dev. 15, 214–225. https://doi.org/10.1108/wjstsd-11-2017-0042

Stritzke, S., Jain, P., 2021. The sustainability of decentralised renewable energy projects in developing countries: Learning lessons from Zambia. Energies 14. https://doi.org/10.3390/en14133757

Sumba, C., Owiny, A., Ouma, K., Matakala, N., Concilia, M., Chirwa, P., Syampungani, S., 2021. Ecofootprint of Charcoal Production and Its Economic Contribution Towards Rural Livelihoods in Sub-Saharan Africa. pp. 445–472. https://doi.org/10.1007/978-981-15-9496-0_15

Szabó, S., Pinedo Pascua, I., Puig, D., Moner-Girona, M., Negre, M., Huld, T., Mulugetta, Y., Kougias, I., Szabó, L., Kammen, D., 2021. Mapping of affordability levels for photovoltaic-based electricity generation in the solar belt of sub-Saharan Africa, East Asia and South Asia. Sci. Rep. 11, 1–14. https://doi.org/10.1038/s41598-021-82638-x

Tambatamba, A., Kumwenda, B., 2018. Sustainable Electrification System for Rural Farms in Zambia: A Case Study of a Farm in Lufwanyama. 2018 IEEE PES/IAS PowerAfrica, PowerAfrica 2018 444–450. https://doi.org/10.1109/PowerAfrica.2018.8521096

Tanyanyiwa, V.I., Kanyepi, T., Katanha, A., 2022. Zimbabwe's Pfumvudza Agriculture Programme---Reality or Rhetoric?, in: Leal Filho, W., Kovaleva, M., Popkova, E. (Eds.), Sustainable Agriculture and Food Security. Springer International Publishing, Cham, pp. 327–347. https://doi.org/10.1007/978-3-030-98617-9_19

Tariq, G.H., Ashraf, M., Hasnain, U.S., 2021. Solar Technology in Agriculture. Technol. Agric. 11, 13.

Taruvinga, A., Jonga, S., Zamisa, O., Forbanka, D.N., 2023. Rural women's participation in wild honey hunting and associated income, dietary diversity, and food insecurity implications: Evidence from South Africa. Cogent Econ. Financ. 11. https://doi.org/10.1080/23322039.2023.2282864

Taylor, M., 2024. The Power of Energy Justice for Rural Communities, in: Heffron, R.J., de Fontenelle, L. (Eds.), The Power of Energy Justice & the Social Contract. Springer Nature Switzerland, Cham, pp. 129–135. https://doi.org/10.1007/978-3-031-46282-5_18

Tazebew, E., Sato, S., Addisu, S., Bekele, E., Alemu, A., Belay, B., 2023. Improving traditional charcoal production system for sustainable charcoal income and environmental benefits in highlands of Ethiopia. Heliyon 9, e19787. https://doi.org/https://doi.org/10.1016/j.heliyon.2023.e19787

Tembo, T.S., Mulenga, P.B., Sitko, N., 2015. Cooking Fuel Choice in Urban Zambia : Implications on Forest Cover by Solomon T . Tembo , Brian P . Mulenga , and Nicholas Sitko Working Paper No 94 March 2015.

Temesgen, M., Getahun, A., Lemma, B., 2019. Livelihood Functions of Capture Fisheries in Sub-Saharan Africa: Food Security, Nutritional, and Economic Implications. Rev. Fish. Sci. Aquac. 27, 215–225. https://doi.org/10.1080/23308249.2019.1565754

Timko, J.A., Waeber, P.O., Kozak, R.A., 2010. The socio-economic contribution of non-timber forest products to rural livelihoods in Sub-Saharan Africa: Knowledge gaps and new directions. Int. For. Rev. 12, 284–294. https://doi.org/10.1505/ifor.12.3.284

Timmermann, L., Smith-Hall, C., 2019. Commercial Medicinal Plant Collection Is Transforming High-altitude Livelihoods in the Himalayas. Source Mt. Res. Dev. 39, 13–21. https://doi.org/10.2307/26915076

Tinta, A.A., Sylla, A.Y., Lankouande, E., 2023. Solar PV adoption in rural Burkina Faso. Energy 278. https://doi.org/10.1016/j.energy.2023.127762

Togarepi, C., Nashidengo, E., Siyambango, N., 2020. Effects of Climatic Variability and Non-Climatic Factors on Mopane Worms' (Gonimbrasia Belina) Distribution and Livelihood Options in North Central Namibia. Environ. Nat. Resour. Res. 10, 14. https://doi.org/10.5539/enrr.v10n2p14

Tomala, J., Mierzejewski, M., Urbaniec, M., Martinez, S., 2021. Towards sustainable energy development in sub-saharan africa: Challenges and opportunities. Energies 14. https://doi.org/10.3390/en14196037

Tong, T.M., Asare, J., Rwenyagila, E.R., Anye, V., Oyewole, O.K., Fashina, A.A., Soboyejo, W.O., 2015. A Study of factors that influence the adoption of solar powered lanterns in a rural village in Kenya. Perspect. Glob. Dev. Technol. 14, 448–491. https://doi.org/10.1163/15691497-12341356

Tornel-Vázquez, R., Iglesias, E., Loureiro, M., 2024. Adoption of clean energy cooking technologies in rural households: the role of women. Environ. Dev. Econ. 499–517. https://doi.org/10.1017/S1355770X24000226

Tovar-ortiz, S.A., Rodriguez-gonzalez, P.T., 2024. Modeling the Impact of Global Warming on Ecosystem Dynamics : A Compartmental Approach to Sustainability 1077–1100. https://doi.org/https://doi.org/10.3390/world5040054

Turner, R.J., 2007. Diffusion of Innovations, Everett M. Rogers, 5th edition, Free Press, New York, NY (2003), 551 pages. J. Minim. Invasive Gynecol. 14, 776. https://doi.org/10.1016/J.JMIG.2007.07.001

Tweddle, D., Cowx, I.G., Peel, R.A., Weyl, O.L.F., 2015. Challenges in fisheries management in the Zambezi, one of the great rivers of Africa. Fish. Manag. Ecol. 22, 99–111. https://doi.org/10.1111/fme.12107

Tyagi, J., Ahmad, S., Malik, M., 2022. Nitrogenous fertilizers: impact on environment sustainability, mitigation strategies, and challenges. Int. J. Environ. Sci. Technol. 19, 11649–11672. https://doi.org/10.1007/s13762-022-04027-9

Tyagi, V. V., Pathak, S.K., Chopra, K., Saxena, A., Kalidasan, B., Dwivedi, A., Goel, V., Sharma, R.K., Agrawal, R., Kandil, A.A., Awad, M.M., Kothari, R., Pandey, A.K., 2024. Sustainable growth of solar drying technologies: Advancing the use of thermal energy storage for domestic and industrial applications. J. Energy Storage 99, 113320. https://doi.org/10.1016/j.est.2024.113320

Tyukavina, A., Potapov, P., Hansen, M.C., Pickens, A.H., Stehman, S. V., Turubanova, S., Parker, D., Zalles, V., Lima, A., Kommareddy, I., Song, X.P., Wang, L., Harris, N., 2022. Global Trends of Forest Loss Due to Fire From 2001 to 2019. Front. Remote Sens. 3, 1–20. https://doi.org/10.3389/frsen.2022.825190

UN-ITAR, 2024. Global E-waste Monitor, International Telecommmunication Union (ITU) and United Nations Institute for Training and Research (UNITAR), Geneva/Bonn. https://doi.org/https://ewastemonitor.info/the-global-e-waste-monitor-2024/

UN-REDD+, 2024. Forest loss and agricultural expansion : a point of no return for ecosystems and rainfall patterns [WWW Document]. United Nations Blog. URL https://www.un-redd.org/post/forest-loss-and-agricultural-expansion-point-no-return-ecosystems-and-rainfall-patterns (accessed 8.17.25).

UNECE, 2024. Critical Minerals for the Sustainable Energy Transition. A Guidebook to Support Intergenerational Action, 1st ed, United Nations Publications. Geneva.

UNODC, 2025. Global Analysis on Crimes that Affect the Environment - Part 2a: Forest Crimes: Illegal deforestation and logging. United Nations Publ. https://doi.org/https://www.unodc.org/documents/data-and-analysis/Crimes%20on%20Environment/ECR25_P2a_Deforestation.pdf

USAID A2C, 2024. USAID Alternatives to Charcoal (A2C) [WWW Document]. USAID Bull. Catherine. URL https://www.usaid.gov/zambia/fact-sheet/alternatives-charcoal%0D (accessed 1.20.25).

USAID A2C, 2021. USAID / Zambia ECONOMIC DEVELOPMENT ALTERNATIVES TO CHARCOAL (A2C) [WWW Document]. USAID Bull. URL https://www.ecorys.com/app/uploads/files/2021-04/A2C_Fact Sheet 2021_FINAL.pdf (accessed 2.11.25).

Usmani, A.W., Alam, M.S., Rafat, Y., Saidan, I. Al, 2020. An IoT based Solution to Avoid Venting in Lithium Ion Battery Due to Overcharging, in: 2020 5th IEEE International Conference on Recent Advances and Innovations in Engineering (ICRAIE). pp. 1–5. https://doi.org/10.1109/ICRAIE51050.2020.9358369

Utoh Imo-Obong, Ekpotu, W., Obialor, M.C., 2024. Assessing the Viability and Impact of Off Grid Systems for Sustainable Electrification of Rural Communities in Sub-Saharan Africa. SPE Niger. Annu. Int. Conf. Exhib. 2024.

Valero, A., Valero, A., Calvo, G., 2021. Summary and critical review of the International Energy Agency’s special report: The role of critical minerals in clean energy transitions. Rev. Metal. 57. https://doi.org/10.3989/REVMETALM.197

Van Stan, J.T., Dymond, S.F., Klamerus-Iwan, A., 2021. Bark-Water Interactions Across Ecosystem States and Fluxes. Front. For. Glob. Chang. 4, 1–8. https://doi.org/10.3389/ffgc.2021.660662

van Vliet, N., Massé, F., Muhindo, J., Nyumu, J., Mbangale, E., Shephard, S., 2024. Wild animal attacks and other occupational risks perceived by Indigenous hunters and fishers in the Yangambi landscape. Hum. Dimens. Wildl. 00, 1–14. https://doi.org/10.1080/10871209.2024.2394595

Vanadzina, E., Pinomaa, A., Honkapuro, S., Mendes, G., 2019. An innovative business model for rural sub-Saharan Africa electrification. Energy Procedia 159, 364–369. https://doi.org/10.1016/j.egypro.2019.01.001

Vanbergen, A.J., Breeze, T.D., Heard, M.S., Breeze, T., Potts, S.G., Hanley, N., 2014. Status and value of pollinators and pollination services Pollinators and Pollination Services STATUS AND VALUE OF POLLINATORS AND POLLINATION SERVICES A REPORT TO THE DEPARTMENT FOR ENVIRONMENT, FOOD AND RURAL AFFAIRS (Defra).

Vanegas Cantarero, M.M., 2020. Of renewable energy, energy democracy, and sustainable development: A roadmap to accelerate the energy transition in developing countries. Energy Res. Soc. Sci. https://doi.org/10.1016/j.erss.2020.101716

Veen, H., Eppinga, M., Mwampamba, T., Santos, M., 2021. Long term impacts of transitions in charcoal production systems in tropical biomes. Environ. Res. Lett. 16. https://doi.org/10.1088/1748-9326/abe14d

Venkatesh, V., Davis, F.D., 2000. Theoretical extension of the Technology Acceptance Model: Four longitudinal field studies. Manage. Sci. 46, 186–204. https://doi.org/10.1287/mnsc.46.2.186.11926

Verma, H., 2015. AN AGRICULTURAL POLLUTANT : CHEMICAL FERTILIZER – A REVIEW. https://doi.org/https://api.semanticscholar.org/CorpusID:199524711

Vigne, R., 2022. School of Wildlife Conservation End of Year Report 2022. Kigali.

Walker, G., Devine-Wright, P., 2008. Community renewable energy: What should it mean? Energy Policy 36, 497–500. https://doi.org/10.1016/j.enpol.2007.10.019

Walling, E., Vaneeckhaute, C., 2021. Nitrogen fertilizers and the environment, Nitrate Handbook: Environmental, Agricultural, and Health Effects. https://doi.org/10.1201/9780429326806-8

Wang, L., Mondela, C.L., Kuuluvainen, J., 2022. Striking a Balance between Livelihood and Forest Conservation in a Forest Farm Facility in Choma, Zambia. Forests 13. https://doi.org/10.3390/f13101631

Wanodyo, S., 2012. Encountering Development: The Making and Unmaking of the Third World. Princet. Univ. Press.

Wassie, Y.T., Adaramola, M.S., 2021. Socio-economic and environmental impacts of rural electrification with Solar Photovoltaic systems: Evidence from southern Ethiopia. Energy Sustain. Dev. 60, 52–66. https://doi.org/10.1016/J.ESD.2020.12.002

Wassie, Y.T., Ahlgren, E.O., 2023. Determinants of electricity consumption from decentralized solar PV mini-grids in rural East Africa: An econometric analysis. Energy 274, 127351. https://doi.org/10.1016/j.energy.2023.127351

Wassie, Y.T., Rannestad, M.M., Adaramola, M.S., 2021. Determinants of household energy choices in rural sub-Saharan Africa: An example from southern Ethiopia. Energy 221, 119785. https://doi.org/10.1016/j.energy.2021.119785

White, P.A., Belant, J.L., 2015. Provisioning of game meat to rural communities as a benefit of sport hunting in Zambia. PLoS One 10, 1–13. https://doi.org/10.1371/journal.pone.0117237

Wicander, S., Coad, L., 2018. Can the Provision of Alternative Livelihoods Reduce the Impact of Wild Meat Hunting in West and Central Africa? Conserv. Soc. 16. https://doi.org/10.4103/cs.cs_17_56

Williams, N.J., Jaramillo, P., Taneja, J., Ustun, T.S., 2015. Enabling private sector investment in microgrid-based rural electrification in developing countries: A review. Renew. Sustain. Energy Rev. 52, 1268–1281. https://doi.org/10.1016/J.RSER.2015.07.153

Winklmaier, J., Bazan Santos, S., 2018. Promoting Rural Electrification in Sub-Saharan Africa: Least-Cost Modelling of Decentralized Energy-Water-Food Systems: Case Study of St. Rupert Mayer, Zimbabwe. Springer International

Publishing. https://doi.org/10.1007/978-3-319-93438-9_6

Wolske, K.S., Gillingham, K.T., Schultz, P.W., 2020. Peer influence on household energy behaviours. Nat. Energy 5, 202–212. https://doi.org/10.1038/s41560-019-0541-9

World Economic Forum, 2024. Securing Minerals for the Energy Transition : Unlocking the Value Chain through Policy , Investment and Innovation. World Econ. Forum.

World Energy Outlook, 2024. World Energy Outlook 2024 23–28.

World Energy Outlook, 2020. World Energy Outlook 2020 2050, 1–461.

Xie, H., Ringler, C., Mondal, M.A.H., 2021. Solar or Diesel: A Comparison of Costs for Groundwater-Fed Irrigation in Sub-Saharan Africa Under Two Energy Solutions. Earth's Futur. 9. https://doi.org/10.1029/2020EF001611

Yalew, A.., 2015. The Perplex of Deforestation in sub-Saharan Africa. J. Trop. For. Environ. 5, 19–30. https://doi.org/10.31357/jtfe.v5i1.2494

Yekini, S.M., Guiawa, M., Onyegbadue, I.A., Olowoniyi, F., 2024. Assessment of Sustainable Energy for Agricultural Energy Provision in Rural Sub-Saharan Africa. African J. Agric. Sci. Food Res. 15, 61–76. https://doi.org/10.62154/sz7j2452

Yunusa, S.U., Mensah, E., Preko, K., Narra, S., Saleh, A., Sanfo, S., Isiaka, M., Dalha, I.B., Abdulsalam, M., 2023. Biomass cookstoves: A review of technical aspects and recent advances. Energy Nexus 11, 100225. https://doi.org/10.1016/j.nexus.2023.100225

Yusuff, A.Q., 2014. NTFPs Collection as an Alternative Source of Income for Poverty Alleviation among Rural Farmers in Egbeda Local Government Oyo State. Acad. J. Interdiscip. Stud. https://doi.org/10.5901/ajis.2014.v3n6p467

Zaini, A.M.A., Mohamad, N.A., 2015. Activated charcoal for oral medicinal purposes: Is it really activated? J. Appl. Pharm. Sci. 5, 157–159. https://doi.org/10.7324/JAPS.2015.501028

Zambia Statistics Agency (ZamStats), 2025. Monthly Inflation Bulletin Jan 2025. Zambia Stat. Agency 262, 1–49.

Zambia Wildlife Act of 2015, 2015. Wildlife Act of 2015, No. 14. Repub. Zambia Gov. Gaz. 311–412.

ZamStats, 2022. 2022 Census of population and housing preliminary report: Republic of Zambia. Zambia Stat. Agency 1–39. https://doi.org/https://www.zamstats.gov.zm/wp-content/uploads/2023/12/2022-Census-of-Population-and-Housing-Preliminary.pdf

ZESCO, 2024a. ZESCO Power Rationing Schedule (Aug 2024) [WWW Document]. ZESCO Off. Website Press Release. https://doi.org/https://www.zesco.co.zm/media_releases.php

ZESCO, 2024b. ZESCO POWER SUPPLY UPDATE [WWW Document]. ZESCO Off. Website Press Release.

https://doi.org/https://www.zesco.co.zm/media_releases.php

ZNCAF, 2023. Zambia Natural Capital Accounts for Forests. Lusaka. https://doi.org/https://www.wavespartnership.org/sites/waves/files/kc/Zambia%20Natural%20Capital%20Accounts%20for%20Forests_Technical%20Report%202016-2020%20FINAL%20FOR%20WEB.pdf

Zulu, D., Ellis, R.H., Culham, A., 2019. Collection, Consumption, and Sale of Lusala (Dioscorea hirtiflora)—a Wild Yam—by Rural Households in Southern Province, Zambia. Econ. Bot. 73, 47–63. https://doi.org/10.1007/s12231-018-9433-3

Zulu, E., 2016. Creating solar communities as a way of mitigating Zambia's power (Energy) crisis, in: 2016 IEEE PES PowerAfrica. p. 72. https://doi.org/10.1109/PowerAfrica.2016.7556573

Zulu, S., Zulu, E., Chabala, M., 2022. Factors influencing households' intention to adopt solar energy solutions in Zambia: insights from the theory of planned behaviour. Smart Sustain. Built Environ. 11, 951–971. https://doi.org/10.1108/SASBE-01-2021-0008

Zulu, S.L., Chabala, M., Zulu, E., 2021. Perceptions and beliefs influencing intention to use solar energy solutions in Zambian households. Built Environ. Proj. Asset Manag. 11, 918–933. https://doi.org/10.1108/BEPAM-01-2021-0010

Appendices

Appendix A: RUDSHAM Policy Implementation Wheel

Operationalisation Steps of RUDSHAM (Policy makers and implementors guide)

Below is a structured RUDSHAM WHEEL framework for practical implementation with the points rearranged in a logical sequence for solar PV implementation projects in rural Zambia. This rearrangement starts with foundational elements like policy support and economic considerations, followed by financial models and community participation. It then addresses social norms and perceived behaviour control, ensuring that technological and practical aspects are thoroughly understood and simplified. Finally, it considers prior preferences and environmental concerns, ensuring a comprehensive approach to implementing solar PV projects. Only a score of 100% and total interconstruct interaction analysis at each stage would be desirable to increase chances of project acceptance, social influence and success. It is termed wheel because the process needs to be ongoing.

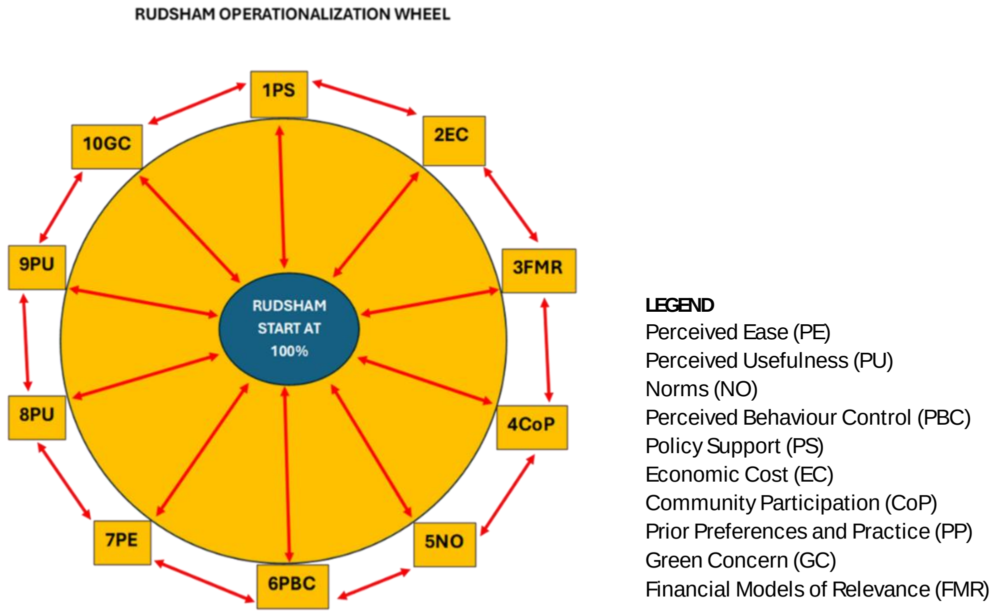

Figure 44: RUDSHAM Operationalisation Wheel

1. Policy Support (PS)
- Review government incentives.
- Assess subsidy impacts.
- Evaluate supplier support.
- Communicate policy benefits.
- Facilitate external support.

2. Economic Cost (EC)
- Analyse upfront costs.
- Assess household budget impact.
- Compare traditional energy costs.

- Identify financial barriers.
- Propose cost-effective solutions.

3. Financial Models of Relevance (FMR)
    - Compare local finance practices.
    - Analyse global solar PV models.
    - Assess financial model impacts.
    - Identify applicable approaches.
    - Propose sustainable finance options.
4. Community Participation (CoP)
    - Encourage design involvement.
    - Promote community financing.
    - Facilitate maintenance roles.
    - Foster collective ownership.
    - Assess participation levels.
5. Norms (NO)
    - Identify influential community members.
    - Observe social learning patterns.
    - Assess peer influence on adoption.
    - Promote key opinion leaders.
    - Leverage household norms.
6. Perceived Behaviour Control (PBC)
    - Survey purchase decision control.
    - Evaluate warranty availability.
    - Analyse configuration options.
    - Measure autonomy perceptions.
    - Address control-related barriers.
7. Perceived Ease (PE)
    - Survey ease of installation.
    - Collect feedback on usability.
    - Identify maintenance challenges.
    - Analyse responses for complexity barriers.
    - Simplify technological aspects.
8. Perceived Usefulness (PU)
    - Gather community feedback on benefits.
    - Assess reliability perceptions.
    - Evaluate energy security benefits.
    - Measure practical advantages.
    - Link benefits to community trust.
9. Prior Preferences and Practice (PP)
    - Survey existing energy practices.
    - Identify key energy uses.
    - Measure potential shift.

- Compare with solar PV options.
- Understand historical preferences.

10. Green Concern (GC)
    - Assess individual environmental awareness.
    - Evaluate household green practices.
    - Measure community concern levels.
    - Link motivations to solar PV.
    - Promote environmental benefits.

Appendix B: RUDSHAM Framework Attributes Description

Below is a description of how each attribute of the RUDSHAM framework helped to inform the study:

1. Perceived Ease (PE)

   Encompasses the ease of installation, use, maintenance, and access to experts for support. PE helped assess the ease of installing, maintaining, and accessing technical support for solar PV systems in Zambia. Data on rural households' experiences with technical challenges, usability, and maintenance frequencies was gathered to evaluate the systems' practicality in remote settings.

2. Perceived Usefulness (PU)

   Factors include the technology's dependability, reliability, energy security, improvement over existing power sources, and productive use. PU guided data collection on solar PV's reliability, energy security, and economic productivity. For rural Zambian households, data on how solar PV systems improve livelihoods, such as supporting small businesses, agriculture, or reducing dependency on unreliable grid power, provided insight into its overall usefulness.

3. Norms (NO)

   Compatibility with social norms, household norms, social acceptability, and the influence of people's opinions and experiences. NO assisted in capturing data on social and household energy use norms and the influence of peer networks on solar PV adoption. Surveys assessed how societal acceptance and household attitudes toward solar PV align with cultural expectations and neighbour experiences, influencing adoption decisions.

4. Perceived Behaviour Control (PBC)

   The availability of return warranties, choice in configuration, guarantees, and the freedom and ability to choose to buy. PBC directed data extraction on consumer confidence in purchasing solar PV systems. Information on the availability of warranties, flexibility in system configurations, and rural households' freedom to choose specific systems helped assess how these factors influence adoption rates and behaviour.

5. Policy Support (PS)

   Includes incentives, subsidies, government support, alignment with UNSDGs, support from solar PV suppliers, and effective communication. PS aided in collecting data on government policies, subsidies, and solar suppliers' roles. In Zambia, insights into policy alignment with SDGs, the presence of subsidies, and communication efforts by suppliers revealed barriers and facilitators to widespread solar PV adoption in rural areas.

6. Economic Cost (EC)

   The price of solar PV systems and its impact on the decision to buy (adopt solar PV) and overall energy expenditure. EC focused on gathering data regarding the costs associated with solar PV systems and their influence on energy expenditure. Surveying rural households' affordability perceptions, financing options, income generating activities and energy savings after adoption provided a clear picture of economic viability in Zambia.

7. Community Participation (CoP)

   The extent of community ownership and involvement in designing, financing, and maintaining solar PV systems, as well as supplier engagement. CoP emphasised collecting data on community involvement in solar PV projects. Information on community-led design, financing, and system maintenance, as well as the role of local suppliers, was essential to understanding the sustainability and long-term success of solar PV systems.

8. Prior Preferences and Practice (PP)

   Current energy practices, preferences, key uses of energy, reasons for these preferences, and expectations. PP guided data on previous energy practices, like using biomass or kerosene, and the motivations behind these preferences. The related challenges were also explored. Understanding these historical patterns was vital in identifying the hurdles to transitioning to solar PV, as well as households' energy expectations.

9. Green Concern (GC)

   Environmental concern and awareness of the impact at individual, household, and community levels. Deals with sustainability aspects connected to various practices and income generating activities. GC facilitated data collection on environmental awareness at both the household and community levels. The surveys gauged the degree of environmental concern and impact among rural Zambian households, particularly regarding deforestation and carbon emissions, motivating a shift toward solar PV.

10. Financial Models of Relevance (FMR)

    Comparison of current finance practices with other relevant solar PV financial models globally and their applicability in the developing world context. Sources of finance for adopting/upgrading solar PV systems. FMR assisted in extracting data on financing methods for solar PV adoption, comparing global models to local practices. Gathering information on microfinance, community savings schemes, or pay-as-you-go systems helped assess their suitability for expanding solar PV in rural Zambia.

Appendix C: RUDSHAM General Interview Protocol

a) Social Demographics (SD)

1) Age:
   - Below 18 years
   - 19 to 35 years
   - 36 to 45 years
   - 46 to 55 years
   - 56 years and above
2) Gender:
   - Male
   - Female
   - Other
3) Income (Monthly in ZMW, $1 = K25):
   - Below K5,000
   - K5,001 – K10,000
   - K10,001 – K20,000
   - Above K20,000
4) Marital Status:
   - Married
   - Widowed
   - Single
   - Divorced
5) Education Level:
   - Bachelor's Degree
   - Diploma
   - College Certificate
   - High School Certificate
   - Grade 9 and below
   - None

b) Perceived Ease of Use (PE) (Ease of installation, use, maintenance, and access to expertise)

1) How easy is it to install solar PV panels?
2) What are the main uses of solar PV power in your household or community?
3) How do you maintain your solar PV system?
4) What challenges have you faced in maintaining solar PV systems?
5) How accessible are solar PV experts in your area?
6) What type of training or support would you require for solar PV maintenance?
7) Are there any technical challenges you face with solar PV installation and maintenance?

c) Perceived Usefulness (PU) (Dependability, reliability, security, and productive use)

1) How often do you use solar PV energy in your daily activities?
2) How reliable do you find solar PV systems compared to other energy sources?
3) What is your experience with solar energy availability in different seasons?
   - Rainy season
   - Cold season
   - Hot season
4) What safety concerns do you have regarding solar PV systems in terms of:
   - Theft
   - Fire hazards
   - Vandalism
   - Counterfeit products
   - Damage to property
5) How has solar PV energy improved your productivity (e.g., farming, business, education)?
6) What infrastructure challenges exist for solar PV adoption in your community?

d) Social Norms (SN) (Compatibility, social acceptance, and perceptions)

1) What challenges do you face when installing solar PV panels on rooftops or in open spaces?
2) How well do you think solar PV technology fits into your community's way of life?
3) Apart from solar energy, what other power sources do people commonly use?
4) How accepted is solar energy within your community?
5) What are the general opinions and experiences of people regarding solar PV adoption?
6) Are there cultural or social beliefs that discourage solar PV adoption in your community?

e) Perceived Behavioural Control (PBC) (Freedom to choose configurations, warranties, and guarantees)

1) Do solar PV systems come with return warranties and guarantees?
2) What level of freedom do you have in selecting different solar PV system configurations?
3) To what extent do external factors (e.g., market trends, community influence, or policy incentives) influence your decision to purchase solar PV systems?
4) Do you think misinformation or lack of awareness affects people's willingness to adopt solar PV?

f) Policy Support (PS) (Government, NGOs, incentives, subsidies, and information dissemination)

1) What type of support do you receive from the government regarding solar PV adoption?
2) What kind of assistance do aid agencies provide in solar energy adoption?
3) What challenges do you face in accessing government or NGO solar energy programmes?

4) What kind of policy or financial support would make it easier for you to adopt solar PV?
5) How effective is information dissemination on solar PV technology in rural areas?

g) Economic Cost (EC) (Affordability, maintenance, and cost savings)

1) What are your thoughts on the pricing of solar PV systems?
2) What are the key maintenance costs associated with owning a solar PV system?
3) How does using solar PV energy help you save on electricity or fuel costs?
4) How does the price of solar PV systems influence your decision to buy?
5) What are the major financial challenges you face in adopting solar PV systems?

h) Community Participation (CoP) (Community ownership, involvement, and supplier engagement)

1) Can you describe any successful community-led solar projects you know of?
2) Do you think community ownership of solar PV projects is important? Why?
3) To what extent is the community consulted when designing solar PV projects?
4) How well do government agencies, NGOs, suppliers, and tech companies consider community opinions when implementing solar PV initiatives?

i) Prior Preferences and Practices (PP) (Current energy sources, transition process, and expectations)

1) What are the most important uses of energy in your community?
2) What energy source do you prefer, and why?
3) How did you come to adopt your current energy source(s)?
4) What negative effects have you experienced with your current energy sources?
5) How would you like to improve your current energy access?
6) What advantages does solar energy have over other energy sources?
7) To what extent do you think solar PV can replace your current energy source?

j) Green Concern (GC) (Environmental awareness, conservation efforts, and sustainability challenges)

1) What awareness do you have about environmental conservation?
2) What steps do you take to protect the environment in your household or community?
3) How does your community contribute to environmental conservation?
4) How does the government support environmental sustainability efforts?
5) What are the negative consequences of neglecting environmental conservation?
6) What challenges do you face in environmental conservation efforts?
7) How does deforestation affect food security in your area?

k) Financial Models of Relevance (FMR) (Affordability, financing mechanisms, and partnerships)

1) How did you finance your solar PV system?

2) What are your primary sources of income?
3) What financing models (e.g., loans, pay-as-you-go, leasing) are you aware of?
4) Which financing model would you prefer for solar PV acquisition?
5) Do you think your community has the capacity to participate in public-private partnerships for solar projects?
6) What kind of contributions would you prefer to make in a solar energy partnership?
    - Financial
    - Material
    - Labour
    - Other
7) How much would you be willing to pay per month for off-grid solar power?
8) If solar loans were provided, would you take one? If yes, what repayment method would you prefer?
9) Would you prefer a solar energy plant (community-based) or individual household solar systems? Why?
10) Would you be willing to participate in a solar community around a shared solar plant? Why or why not?
11) Would you prefer a postpaid or prepaid solar energy system?

Appendix D: Calculations of Forest Carbon Stock and Sequestration

Table 54: Zambia's Forest Carbon Stock and Sequestration Calculations

Forest Fire										
Carbon Stock Loss	**Zambia**		**Chingola**		**Kapiri Mposhi**		**Mkushi**		**Chongwe**	
	2008~2015	2016~2023	2008~2015	2016~2023	2008~2015	2016~2023	2008~2015	2016~2023	2008~2015	2016~2023
Forest area loss due to Forest Fire (ha)	4,975.18	10,374.64	0.21	0.03	43.53	37.33	6.16	2.99	1.26	5.12
AGB (t/ha)	69.6	69.6	69.6	69.6	69.6	69.6	69.6	69.6	69.6	69.6
Emission Factor	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Carbon Fraction	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Carbon stock loss(tC)	81,374	169,687.60	3.44	0.53	711.91	610.56	100.79	48.90	20.58	83.77
Carbon stock loss (tCO_2)	298,642	622,753.49	12.64	1.94	2,612.70	2,240.74	369.90	179.46	75.53	307.45
Future Carbon Sequestration loss	**Zambia**		**Chingola**		**Kapiri Mposhi**		**Mkushi**		**Chongwe**	
	2008~2015	2016~2023	2008~2015	2016~2023	2008~2015	2016~2023	2008~2015	2016~2023	2008~2015	2016~2023
Forest area loss (ha)	4,975.18	10,374.64	0.21	0.03	43.53	37.33	6.16	2.99	1.26	5.12
AGB Growth Rate (t/ha/yr）	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Carbon Fraction of	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Future Carbon Sequestration Loss (tC/yr)	3,741.33	7,801.73	0.16	0.02	32.73	28.07	4.63	2.25	0.95	3.85
Future Carbon Sequestration Loss (tCO_2 /yr)	13,730.69	28,632.34	0.58	0.09	120.12	103.02	17.01	8.25	3.47	14.14

Charcoal and Fuelwood										
Carbon Stock Loss	**Zambia**		**Chingola**		**Kapiri Mposhi**		**Mkushi**		**Chongwe**	
	2008~2015	2016~2023	2008~2015	2016~2023	2008~2015	2016~2023	2008~2015	2016~2023	2008~2015	2016~2023
Forest area loss (ha)	620,733	1,074,226	2,502	5,611	18,985	38,765	20,226	40,804	3,377	6,431
% of Forest Loss: Charcoal/Fuelwood	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
Forest Loss: Charcoal/Fuelwood (ha)	558,660	966,803	2,252	5,050	17,087	34,889	18,203	36,724	3,039	5,788
AGB (t/ha)	69.6	69.6	69.6	69.6	69.6	69.6	69.6	69.6	69.6	69.6
Emission Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Carbon Fraction of Aboveground Biomass	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Carbon stock loss (tC)	18,274,876	31,626,073	73,661	165,192	558,934	1,141,273	595,470	1,201,302	99,422	189,334
Carbon stock loss (tCO_2)	67,068,795	116,067,687	270,335	606,256	2,051,286	4,188,470	2,185,374	4,408,780	364,877	694,855
Future Carbon Sequestration loss	**Zambia**		**Chingola**		**Kapiri Mposhi**		**Mkushi**		**Chongwe**	
	2008~2015	2016~2023	2008~2015	2016~2023	2008~2015	2016~2023	2008~2015	2016~2023	2008~2015	2016~2023
Forest Loss: Charcoal/Fuelwood	558,660ha	966,803ha	2,252ha	5,050ha	17,087ha	34,889ha	18,203ha	36,724ha	3,039ha	5,788ha
AGB Growth Rate (t/ha/yr）	1.6t	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6

Carbon Fraction	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Future Carbon Sequestration Loss (tC/yr)	420,112	727,036	1,693.35	3,797.52	12,849.05	26,236.15	13,688.96	27,616.15	2,285.55	4,352.50
Future Carbon Sequestration Loss (tCO_2 /yr)	1,541,811	2,668,223	6,215	13,937	47,156	96,287	50,238	101,351	8,388	15,974

Table 55: Forest Carbon Stock and Sequestration Potential (Timber harvesting)

Timber Harvesting										
Carbon Stock Loss	**Zambia**		**Chingola**		**Kapiri Mposhi**		**Mkushi**		**Chongwe**	
	2008~2015	2016~2023	2008~2015	2016～2023	2008~2015	2016~2023	2008~2015	2016~2023	2008~2015	2016~2023
Forest area loss (ha)	620,733	1,074,226	2,502	5,611	18,985	38,765	20,226	40,804	3,377	6,431
% of Forest Loss: Timber Harvesting	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
Forest area loss: Timber Harvesting(ha)	18,622	32,227	75	168	570	1,163	607	1,224	101	193
Emission Factor	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carbon Fraction	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Carbon stock loss (tC)	0	0	0	0	0	0	0	0	0	0
Carbon stock loss (tCO_2)	0	0	0	0	0	0	0	0	0	0
Future Carbon Sequestration loss	**Zambia**		**Chingola**		**Kapiri Mposhi**		**Mkushi**		**Chongwe**	
	2008~2015	2016~2023	2008~2015	2016~2023	2008~2015	2016~2023	2008~2015	2016~2023	2008~2015	2016~2023
Forest area loss : Timber Harvesting (ha)	18,622	32,227	75	168	570	1,163	607	1,224	101	193
AGB Growth Rate （t/ha/yr）	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Carbon Fraction	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Future Carbon Sequestration Loss (tC/yr)	14,003.74	24,234.54	56.45	126.58	428.30	874.54	456.30	920.54	76.19	145.08
Future Carbon Sequestration Loss (tCO_2 /yr)	51,393.71	88,940.76	207.15	464.56	1,571.87	3,209.56	1,674.62	3,378.38	279.60	532.46

Appendix E: RUDSHAM Charcoal Burner Interview Protocol

(i) English version

a) Background Information (PP)

1) What is your age, gender, marital status, and family size?
2) How long have you been involved in charcoal production?
3) Who introduced you to charcoal burning and what attracted to it?
4) Are women or youths actively involved in charcoal production in your community?
5) What do you use for cooking and heating?
6) Do you use solar PV products (e.g., solar chargers, solar torches, solar PV lighting systems, solar fridges, solar water pumps) at home or for business?

b) Charcoal Production Process (PP, GC)

1) Can you describe the charcoal production process, including the timeline from start to finish?
2) What types and sizes of trees are preferred for charcoal?
3) How do you ensure sustainability of trees (so that they don't run out)?
4) Are fruit trees, medicinal trees, or other valuable species used for charcoal production?
5) How many bags of charcoal do you produce per week, and how much do you sell weekly or monthly?
6) Are there specific months with higher demand and more profit for charcoal, and what drives this trend?
7) How many kilns (ifibili) do you build every month?
8) What are the measurements in metres (length, width, and height) of a kiln (ichibili)?
9) How many trees (and what size/height) do you need to build a kiln (ichibili) that can produce 25 to 30 bags (in 50kg bags) of charcoal?

c) Risks and Environmental Impact (GC)

1) What are the environmental effects of charcoal production in your area, such as deforestation or soil degradation?
2) Who destroys the forest more; people who clear land for agriculture or those who clear land for charcoal burning? Give reasons for your answer.
3) Have you faced personal risks (e.g., injuries from scorpions or snake bites), health challenges (e.g., coughs, chest pains, headaches, muscle pain), or accidents related to charcoal production?
4) Are there any health issues that charcoal burners commonly experience from exposure to smoke or heat?
5) Do conflicts arise over access to tree harvesting areas? If so, how are they resolved?

d) Social Perception and Norms (NO)

1) How is charcoal production perceived in your community? Are charcoal burners respected or looked down upon?
2) Are there any societal expectations or norms that influence charcoal production, such as gender roles or family obligations?
3) Do chiefs or local leaders regulate charcoal production in your community?
4) Are there medicinal uses for charcoal. Is charcoal used to treat illnesses such as stomach problems, ear problems, poisoning, wounds, or snake bites?

e) Economic Aspects (EC, PU)

1) How much profit do you make per bag of charcoal, and how do you use the income?
2) Do you invest in farming inputs, solar PV systems, or other economic activities using income from charcoal?
3) Can you give examples of solar PV products you have purchased, if any?
4) What other products or investments have you made with charcoal income?
5) How much money do you make from charcoal on a monthly and yearly basis?
6) How much does a big tree cost when bought from local people?

f) Market Dynamics and Logistics (CoP, EC)

1) Who are your primary customers or buyers of charcoal?
2) Do you sell directly to towns, or do you rely on middlemen? If middlemen are involved, why?
3) How do you transport charcoal to market, and what challenges do you face, such as taxes or traffic police?
4) Are there issues of theft or disputes over charcoal bags or resources?

g) Policy Support and Regulation (PS)

1) Does the council or government issue licences or permits for charcoal production? If yes, how much do they cost?
2) Are there any government programmes or incentives supporting alternative energy options like solar PV?
3) Do chiefs, local authorities, or community leaders play a role in controlling or regulating charcoal production?

h) Future Alternatives and Behavioural Control (PBC)

1) If charcoal production were banned, what alternative livelihood would you pursue?
2) What barriers or challenges would you face in adopting solar PV systems or transitioning to other energy sources?

i) Community Participation (CoP, FMR)

1) Are there community-led initiatives or cooperatives involved in designing, financing, or maintaining solar PV systems?
2) Do you think such community involvement would make solar PV systems more accessible or sustainable?

j) Financial Models and Affordability (FMR, EC)

1) How do you finance your energy needs, including charcoal production or solar PV systems?
2) Are there accessible financing options, such as microloans or pay-as-you-go systems, for adopting solar PV?
3) Which companies provide these systems, and how much do they cost?
4) How much does a solar PV system cost with 2 bulbs, 4 bulbs, a radio, TV, and a water pump?
5) What are the prices on a cash and instalments basis?

(ii) Vernacular (Bemba) version

a) UMUFULA WE LYASHI

1) Muli na imyaka inga, abaume/abanakashi, mwalyupa atemwa ukupwa, mwaba banga mu lupwa?
2) Nililali mwatendeke ukoca amalasha?
3) Nibani bamulangilile iyimilimo ya koca amalasha, cinshi camongwele ukutampa ukoca amalasha?
4) Bushe bamaayofwe na imisepeela na bena baliibimbamo mukoca amalasha, mucende mwikalamo?
5) Fintunshi mubomfya pakwipikila na ukukafya ifintu?
6) Bushe mwalitala amubomfyapo ifipe ifipoka amaka yakubomba ukufuma ku kasuba?
7) Bushe mulabomfyapo ifipe ififumya amaka ya kubomba ukufumya kukasuba (amachaja ya musange, amalaiti yabomfya amaka yakasuba, amafiligi yabomba ukubomfya amaka ya kasuba elyo na ma pampu ya bomfya amaka yakasuba) mulabomfya ifiipe pa nganda atemwa mu makwebo?

b) IFYO BACITA PAKOCA AMALASHA

1) Bushe kuti mwalondolola inshita iposeka pa kuputula ifimuti fyakocela amalasha, ukulonga icibili elyo na ukufika kukoca amalasha?
2) Mutundu wa fimutinshi mocela amalasha elyo na ubukulu bwafimuti bubashani, ubomwatemwisha ukocela amalasha?
3) Bushe kwalibako inshila mubombelamo pakutila imiti mupanga taipwile ukocela amalasha?
4) Bushe imiti ilya iikwata ifisabo fyakulya, elyo na imiti babomfya ukundapila amalwele na imiti iyakwata ubunonshi atemwa ubucindami, bushe nayo ilabomfiwa uko cela amalasha?
5) Bushe mifuko inga mukwata ukufuma mumalasha cila mulungu elyo na cila mweshi?
6) Bushe kulabako imyeshi imoimo ilyo amalasha yafwaikwa saana saana, elyo na ukukwatilamo indalama ishingi? Bushe cinshi cilenga cibi ifyo?
7) Bushe fibili finga mupanga cilamweshi?
8) Bushe ifibili filepa shani mulinabutali, mubwipi atemwe mubufumo elyo na intamfu ukuya pamuulu, fibashani?

9) Fimuti finga fiputulwa, ubuukulu nangula mulongapo ifibili ifingafumya imifuko ya 50 kg ukwambila pali 25 ukufika pa 30 imifiko ya malasha?

c) AMASANSO ELYO NEFYO UKOCA AMALASHA KUKUMA ICENDE FILECITIKILAMO

1) Bushe ukoca amalasha kukuma shani icende ukulosha mukupwisha kwakutemaula imiti? Elyo na umushili umuleputaulwa imiti?
2) Bushe nibani bonaulasaana impaanga ukucilamo, abalimi abacita citemene elyo na baputaula imiti yakocela amalasha. Peleni umulandu mwalandila ifyo.
3) Bushe mwalitala amuponenwapo na amasanso ilyo muli mu mpanga pamonga (ukusumwa na kaling'ongo atemwa insoka) Nga ifikumine ubumi bwenu pamonga (ukukola icifuba, ukukalipwa kwa mucifuba, ukubangauka kwa mutwe elyo ukukalipwa kwafilundwa fya mu mubili elyo namasanso yambi yacitika pa mulandu wakoca amalasha?
4) Bushe kulabako amafya ayesa pa mulandu na ukoca amalasha pamonga icushi cifuma ku malasha elyo na icikabilila cifuma kumulilo.
5) Bushe kulaba ukupusana atemwa ukumana pakulwila imiti ya kutem mu mpaanga? Nga cilaifyo musangonshi mupwishishamo amafya yauyu musango?

d) ABANTU BATONTOKANYAPO SHANI PALI UYU MULANDU ELYO NEFYO BASUMINAMO NGA INTAMBI ATEMWA IFISHILANO FYA CIKAYA

1) Bushe ukoca kwa malasha mucende yenu abantu batilaposhani? Bushe aboca amalasha balapelwa umucinshi nagula balabasuusha?
2) Bushe mucende yenu nibani benekelwa ukubomba imilimo ya koca amalasha; baume atemwa banakashi?
3) Bushe abangailila incende yenu pamonga imfumu, bamwine mushi nabambipo, balabikapo ifunde lyakumona ukuti kuli umuyano wa kukonka pa koca amalasha?
4) Bushe kwalibako indawa babomfya ukufuma kumalasha? Bushe amalasha balayabomfya ukundapila amalwele pamonga, mumala, mumatwi elyo nakuli sumu, ifilonda na ukusumwa na insoka?

e) UBUNONSHI BWA MUMALASHA

1) Nishinga indalama musanga pa mufuko umo uwa malasha, kabili mubomfya shani ishindalama nga mwakwata?
2) Bushe mulengisha ishindalama mu makwebo yambi pamonga mubulimi, ukushita imbue, atemwa ukushitamo ifipe ifibomfya amaka yakasuba nangula ku milimo imbi indalama mononkela ukufuma mukoca amalasha?
3) Bushe kuti mwatulangako icipe nangula amakwebo umo mwaingisha indalama ukufuma mu malasha?
4) Fintunshi fimbi mwacitapo ukubomfya indalama sha mu malasha?
5) Nishinga indalama mupanga ukufuma mu malasha cila mweshi elyo na cila mwaka?

6) Bushe mushita shinga icimuti icikulu ku bekanshi ba mucende yenu abene ba mpaanga?

f) AMAKWEBO KU BASHITA AMALASHA NA IFYO CIBA

1) Bushe nibani mushitishako amalasha?
2) Bushe mulaitwalila mwebene amalasha mu misumba atemwa amatauni nangula kulaba abomubomfya ababa pakati,? Nga ebomubomfya, mulandu babelako?
3) Bushe amalasha mutwala shani ku mishiika? Mafyanshi mushingwana nayo? Bushe bakapokola bamucita shani, nga imisonko cibanshani?
4) Bushe kulaba ukumibila imifuko ya malasha, atemwa ukupusana mwebene mweka pa ndalama?

g) AMAFUNDE NA UBUTEKO

1) Bushe ubuteko bwacikaya atemwa kamfulumende alamupela ifitupa fya kocela amalasha;nga ciba ifyo, nishinga ba mulipilisha?
2) Bushe ubuteko bwalibikapo ishila ya bukumu pa kulesha ukoca amalasha pakutila kwaba uku bomfya inshila shimbi ukucila ukoca amalasha?
3) Bushe bashamfumu atemwa abakalmba ba ncende yenu baliibimbamo mu kukondenkanya imilimo ya kulesha ukoca amalasha icoce oce?

h) INSHILA SHIMBI ISHAKUBOMFYA KUNTASHI NA UKUWAMYA IMBELA

1) Ngacakuti balesha ukoca amalasha, ninshilanshi imbi iyo kwingaba ukubomfya?
2) Mafyanshi mwingasanga mukubomfya inshila shimbi ishibomfya amaka ukufuma ku kasuba?

i) UKUISANSHAMO UKWABEKALA CALO

1) Bushe mucende yenu mwalibako utubungwe utwa ibimba mukapanga imifwaile yandalama pa kutila benga sungililabwino ifipe fibomfya amaka ya kasuba
2) Bushe mukutontonkya ukuti utubungwe twa musango nga uyu mukuibimbamo kuti twa sunga ifipe bwino?

j) INSHILA SHAKUSANGILAMO INDALAMA NA UKUKWANISHA

1) Mukwanisha shani ukushita ifyo mubomfya pa kwipikila pamonga amalasha, atemwa ifi bomfya amaka ya kasuba?
2) Bushe kwali bako abapela nsonsela nga balya kuba ukulipilako elyo bamipela amalaiti; Bushe basangwa aba utu twampani?
3) Bushe utwampani tupelo aya makwebo tulasangwa? Kabili nishinga balipilisha indalama? Nga ifintu fishitwa shani umutengo, apali ama babu yabili atemwa yatatu, icilimba, icitushitushi elyo na mashini ya menshi (water pampu). Umutengo ubashani mukulipila pano pano nagu ukuilipila shonse pa muku umo.

Appendix F: Detailed Research Findings A (Chapter 7)

2.0 MOBILE PHONES, SOLAR PV CHARGERS AND SOLAR LIGHTS/TORCHES

Extant literature shows Zambian rural people live on less than $1.9/day (Kalle Hirvonen, Elia Machado, 2024; Mudenda et al., 2023; Sharon Handongwe, 2017) and yet surveying participants in the three rural regions, the following were unveiled:

- The overwhelming majority (>80%) of rural people surveyed own mobile phones, solar PV phone chargers, solar PV lighting systems and/or solar PV torches.
- A substantive share (around 20%) own smart phones
- Rural people surveyed are able to pay for prepaid airtime.
- No land lines are available but only communication towers in rural areas demonstrating technology leapfrogging. (James, 2016, 2012, 2009).

2.1 Improved Coordination

Rural areas face difficulty with respect to reliable communication channels and transportation services posing challenges in communication with agricultural extension officers, market vendors, and coordinating transportation of crops to market efficiently. Prepaid mobile phones provide a solution to this, allowing farmers to easily communicate with each other, as well as providing access support programmes and markets. For example, farmers can use their phones to coordinate the transportation of crops to market, as illustrated by a farmer calling a local truck driver to arrange for the pickup of harvested produce.

Table 56: Improved Coordination Direct Quotations

Participant	*Benefit*	*Illustrative Quote*
Kapiri Interview 3	*Improved communication*	*"I use my phone to coordinate and communicate with others who are important to me."*

The above outcomes are best described by the Perceived Ease (PE) and Community Participation (CoP) attributes of RUDSHAM. Farmers find it easy (PE) to use prepaid mobile phones for communication, facilitating coordination with agricultural officers and vendors. This technology fosters community involvement (CoP) in efficient crop transportation and market transactions, exemplified by farmers coordinating directly with local truck drivers.

2.2 Improved Communication and Coordination

"One Chongwe Interview 2 participant said, 'We use our phones to organise meetings and sensitise the community on many important aspects.'". Poor communication infrastructure and difficulty in face-to-face interaction in the village inhibits efficient coordination and knowledge sharing and this is compounded by geographical constraints.

Prepaid mobile phones allow farmers to communicate with buyers, extension workers, and fellow farmers. They can arrange meetings, discuss agricultural practices, and seek advice.

The results closely align with the Community Participation (CoP) attribute of RUDSHAM. Community participation (CoP) stresses their active engagement in using these tools for mutual benefit and collective action. Improved communication via mobile phones facilitates coordination among farmers and community members, enabling them to organise meetings and share knowledge effectively.

2.3 Access to Market Information

Limited access to market information and difficulty in finding buyers coupled with lack of access to real-time market prices, hinders farmers from making informed decisions about selling crops.

With prepaid mobile phones, farmers can access real-time market prices for their crops, enabling them to make informed decisions about when and where to sell. For instance, a farmer can use their phone to check market prices online or receive SMS alerts about price fluctuations, helping them negotiate better deals, as illustrated by a farmer comparing prices from different buyers before selling their crops.

Table 57: Access to Market Information Direct Quotations

Participant	*Mkushi Interview 2*
Benefit	*Access to market information*
Illustrative Quote	*“We are able to find buyers and tell people that we are selling maize. We use phones to find the best prices for maize.”*

Perceived Usefulness (PU), Economic Cost (EC), and Norms (NO) provide a good description of the results. Real-time market data improves decision-making, demonstrating usefulness; mobile phone accessibility reduces economic barriers; and peer influence on adopting technology for better market access aligns with social norms.

2.4 Profit Maximization and Post - Harvest Loss Reduction

“*A Mkushi Interview 1 participants’ narrative provides insight into how farmers are no longer taken advantage of and abused by Briefcase crop buyers. The briefcase buyers used to take advantage of his ignorance and lack of information to buy crops at giveaway prices which were way below market value. Things have changed since with the coming of phones and technology because he can now access market information and make informed decisions.”* In the absence of market information and uncertainty about the best-selling prices for their crops in different markets, farmers could not obtain up-to-date information on market rates, impacting farmers' decisions on where (place with best price) and when (best time) to sell their produce.

Prepaid mobile phones enable farmers to check market prices for their crops. They can determine whether selling in more distant markets would yield better prices. For example, a farmer can receive a text message with current market rates for maize. Armed with this information, they decide to transport their harvest to a larger town where prices are higher, minimizing post-harvest losses.

The results are best aligned with Perceived Usefulness (PU), Economic Cost (EC), and Norms (NO). Mobile phones enhance decision-making, illustrating usefulness; access to market information improves economic outcomes; and social norms evolve as farmers adopt technology to combat exploitation and optimise profits

2.5 Market Linkages and Networking

Researcher: "How have phones and technology enhanced your market linkages and networking abilities?"

Chongwe Interview 3 female participant: "We can communicate with agriculture extension officers and with other farmers on the best way of farming or storing our crops."

Rural farmers struggled to get agricultural information and extension services making it difficult to form networks for accessing requisite information.

Farmers can join virtual agricultural networks, connect with other farmers, and learn from success stories. These networks provide valuable information on best practices and market trends. Through mobile apps and SMS-based services, prepaid mobile phones provide farmers with valuable agricultural information, including weather forecasts, pest management techniques, and crop cultivation tips. For instance, a farmer can subscribe to an SMS service that provides daily weather updates, helping them plan their farming activities more effectively and minimise crop losses due to adverse weather conditions.

The outcomes are best explained by Perceived Usefulness (PU) and Community Participation (CoP). Mobile phones enhance the practical benefits of market linkages and networking, improving farming practices, and community participation in virtual agricultural networks strengthens collective knowledge and resource sharing among farmers

2.6 Emergency Assistance

In remote areas, it was close to impossible to call for help or medical assistance in times of emergencies such as accidents, medical emergencies, or other critical situations, leading to loss of lives needlessly.

Prepaid mobile phones provide farmers with a lifeline in emergencies, allowing them to call for help or medical assistance when needed. For example, a farmer who encounters a snakebite while working in the fields can quickly dial emergency services for immediate medical attention, potentially saving their life.

Table 58: Emergency Assistance Direct Quotations

Participant	*Benefit*	*Illustrative Quote*
Kapiri Interview 1	*Emergency Assistance*	*"Unlike in old times when we had to run to a land line far away to make a call, nowadays we can quickly call for help in times of emergencies, accidents or fires etc."*

The findings are best described by Perceived Usefulness (PU) and Perceived Behaviour Control (PBC). Mobile phones demonstrate practical benefits by providing critical emergency assistance, enhancing control over emergency responses, and empowering individuals to manage crises effectively.

2.7 Access to Financial Services and Convenient Payment via Mobile Money

Rural farmers suffered from limited access to banking facilities and the inconvenience of cash transactions which posed a huge challenge to farmers. Because of cash transactions, some farmers lost their money through theft, especially in remote areas far from banking facilities.

"The statement of an 80-year-old Kapiri Interview 3 participant highlights the impact of mobile money transactions on financial transaction security and payment convenience. He uses his mobile phone for accessing funds and conducting transactions through mobile money transfers, which are very safe and convenient. He revealed that he no longer needed to hide cash under his bed and did not lose sleep over fear of theft." Buyers can conveniently pay farmers using mobile money services. Even if transportation is a challenge, the farmer can receive payments directly to their phone. Mobile phones enable farmers to access financial services such as mobile banking and money transfers, facilitating secure transactions and savings. As an illustration, a farmer can use their phone to receive payments for their crops directly into their mobile wallet, eliminating the need for cash transactions and reducing the risk of theft or loss.

The above findings are explained by Perceived Usefulness (PU) and Economic Cost (EC). Mobile money services provide practical benefits by enhancing financial transaction security and convenience and reducing the economic burden of cash transactions and the associated risks of theft.

2.8 Social Connectivity

Restricted connectivity and isolation in rural areas hinder social interaction and support networks among farmers. This inhibits social cohesion, knowledge sharing, and collaboration among farmers, weakening community ties.

Prepaid mobile phones enable farmers to stay connected with friends, family, and community members, fostering social cohesion and support networks. As an illustration, a farmer can use their phone to join a WhatsApp group of local farmers, where they can share knowledge, experiences, and resources, strengthening community ties and collaboration.

"Mobile phones help us connect with our friends and relatives very effectively and easily. Sometimes we join WhatsApp groups." (Chongwe Interview 2).

The findings are illustrated by Norms (NO) and Community Participation (CoP). Mobile phones enhance social connectivity and cohesion, fostering knowledge sharing and collaboration among farmers, thereby strengthening community ties and support networks.

2.9 Access to Weather Information and Agricultural Tips

Farmers faced difficulties in planning agricultural activities and mitigating weather-related risks such as floods or droughts.

Farmers can subscribe to weather alerts and receive timely information on planting seasons, irrigation schedules, and pest outbreaks. With advanced weather forecasting equipment, farmers can access information on possible floods or drought alerts along with other prior warning. For example, a farmer might receive an SMS warning about an impending heavy rainstorm which would enable them to quickly cover their crops to prevent damage, thanks to the mobile alert.

Table 59: Access to Weather Information and Agricultural Tips Direct Quotations

Participant	*Benefit*	*Illustrative Quote*
Kapiri Interview 2	*Weather updates*	*"Mobile phones help us get weather related information which helps us to plan and act accordingly…"*

Once a person appreciates the benefits of a service or product, they will find means and ways of raising money to pay for it, even in the absence of donor support. This principle applies to various items such as mobile phones, solar PV lighting systems, and solar PV torches. Notably, no aid agency supplies free solar PV lighting systems, solar torches, or solar chargers. Similarly, no aid agency or external funding provides rural people with free phones or purchases free prepaid talk time for villagers. However, despite the lack of external assistance, individuals have recognised the benefits and necessity of these items, leading them to find ways to purchase them. The above cases of adoption due to necessity can also be observed in the adoption of larger household solar PV systems in rural areas, bypassing the national grid system, much like how landlines were bypassed for mobile phones in remote villages. Through systematic exposure and information dissemination regarding the benefits of solar PV, rural people can be motivated to work hard and acquire these systems instead of waiting for free items.

The results are best explained by Perceived Usefulness (PU) and Perceived Behaviour Control (PBC). Mobile phones enable access to vital weather information and agricultural tips, demonstrating practical benefits and enhancing farmers' control over planning and mitigating risks, leading to proactive decision-making and increased adoption due to recognised value.

Appendix G: Willingness To Pay for Piped Water Case Study

Literature shows Zambian rural people live on less than $1.9/day (Kalle Hirvonen, Elia Machado, 2024; Mudenda et al., 2023; Sharon Handongwe, 2017) and from discussions in our interviews and focus groups, we found:

- Over 85% of rural people in the case study Access Water for Zambia (Water4) were connected to piped water system.
- Most households in the case study (1200) were on prepaid metres
- $40,000 (the equivalent of 125,000 cubic litres) in annual sales were recorded in 2022/23 financial year ($33 per household per year on average)

The rationale for their willingness to pay is discussed below.

3.1 Health and Sanitation Improvements

There is lack of clean and safe drinking water in remote rural areas of Luapula Province which exposes residents to waterborne diseases from contaminated sources like rivers and ponds, occasionally resulting in death.

Piped water systems in remote rural areas of Luapula Province significantly improve health and sanitation by providing access to clean and safe drinking water. This reduces the risk of waterborne diseases such as diarrhea, cholera, and typhoid fever, which are prevalent in communities relying on unsafe water sources like rivers and ponds.

Table 60: Health and Sanitation Improvements Direct Quotation

Participant	*Benefit*	*Illustrative Quote*
Case Study Interview	*Improved Health and Sanitation*	*"Families no longer need to consume contaminated water from rivers or ponds, resulting in fewer instances of waterborne illnesses. This leads to improved overall health and well-being among community members."*

The outcomes are best illustrated by Perceived Usefulness (PU) and Green Concern (GC). Piped water systems in Luapula Province provide practical health benefits by reducing waterborne diseases, enhancing the community's overall well-being, and reflecting a concern for sustainable, clean water solutions.

3.2 Time and Labour Savings

"Previously, villagers, especially women and children, spent hours each day collecting water from distant sources, which hindered their ability to engage in other activities such as education or income-generating work. With piped water systems, the time

spent on water collection is significantly reduced, enabling individuals to pursue other productive endeavors." (Case Study Interview). The narrative above shows the extent to which limited access to clean water sources forces villagers, especially women and children, to spend hours collecting water from distant locations daily, hindering their participation in education or income-generating activities.

Piped water systems save considerable time and labor for residents in remote rural areas by eliminating the need to travel long distances to fetch water. Instead, water is readily available through taps or standpipes near their homes, allowing individuals to allocate their time more efficiently.

The above findings are in line with Perceived Usefulness (PU) and Community Participation (CoP). Piped water systems offer tangible benefits by saving time and labour, enabling women and children to engage in education and income-generating activities. Community involvement in the implementation and maintenance of these systems ensures sustainable and widespread adoption.

3.3 Economic and Social Benefits

Ill health negatively impacts rural communities, hindering agricultural productivity and economic development. Additionally, poor hygiene practices contribute to health issues, increasing healthcare costs.

Piped water systems bring about various economic and social benefits to remote rural communities, including increased agricultural productivity, support for small-scale businesses, and overall community development.

Table 61: Economic and Social Benefits Direct Quotations

Participant	*Case Study Interview*
Benefit	*Economic and Social*
Illustrative Quote	*"Access to clean water promotes better hygiene practices, leading to improved health outcomes and reduced healthcare costs. Additionally, improved water availability enhances agricultural activities, resulting in higher crop yields and increased income for farmers. This, in turn, fosters economic growth and social cohesion within the community."*

The results correspond to Perceived Usefulness (PU) and Community Participation (CoP). The introduction of piped water systems improves health outcomes and enhances agricultural productivity, demonstrating their practical benefits. Community involvement in water system implementation further supports economic growth and social cohesion

3.4 More time for studying socializing and spending time with family

Fetching water consumes valuable time for villagers, limiting opportunities for education, socialization, and family bonding.

“The story of transformed lives of children in the case study interview, shows the impact of piped water in improving rural lives. Children who previously spent hours collecting water now have more time to attend school regularly, complete homework assignments, and participate in extracurricular activities. Similarly, adults have additional time to engage in community gatherings, social events, and recreational activities, strengthening social bonds and family relationships.” Piped water systems free up time for residents to engage in activities such as studying, socializing, and spending quality time with their families, which were previously hindered by the need to fetch water.

The results are linked to Perceived Usefulness (PU) and Community Participation (CoP). Perceived Usefulness highlights the significant improvements in quality of life, such as increased time for education and social activities. Community Participation emphasises the collective benefits and strengthened social bonds facilitated by piped water systems.

3.5 Less exposure to snakes, crocodiles, reptiles, and animal attacks whilst going to collect water and bathing

Researcher: “What other benefits can you share about piped water on the community?”

Case Study Interview Respondent: “Residents no longer need to venture into potentially hazardous environments like rivers or ponds to fetch water, significantly reducing their exposure to wildlife threats. This ensures the safety and well-being of community members, particularly women and children who are most vulnerable to such encounters.”

The above narrative proves that drawing water from rivers or ponds exposes villagers, especially women and children, to risks from wildlife like snakes and crocodiles which either kill, injure or leave people permanently disabled. Piped water systems reduce the risk of encounters with dangerous animals, such as snakes, crocodiles, and other reptiles, during water collection and bathing activities in remote rural areas.

The results correspond with Perceived Usefulness (PU) and Norms (NO). Perceived Usefulness highlights the safety and health benefits of piped water systems, reducing dangerous encounters. Norms emphasise community acceptance and the influence of observing others benefiting from these systems, encouraging broader adoption.

3.6 Observed Individual Benefit

Lack of success stories and observed health benefits from neighbouring communities/houses where piped water systems were implemented successfully caused villages to think the status quo was the best. *"Hearing about neighbouring households where piped water systems have been successfully implemented, residents witness the positive changes in health, sanitation, and overall quality of life experienced by their peers. These success stories serve as tangible examples, inspiring confidence and encouraging adoption of piped water systems." (Case Study Interview).*

Demonstrated success stories and case studies of piped water systems in neighbouring communities or similar contexts influence individuals' perceptions and attitudes towards adopting such systems.

The findings align with Perceived Usefulness (PU) and Norms (NO). Perceived Usefulness is reflected in observing tangible health benefits from neighbouring communities, showcasing the system's utility. Norms highlight how successful implementations in nearby areas influence social acceptance and motivate others to adopt similar systems, driven by observed positive changes.

3.7 Influence of Personal Experience with Piped Water Systems

The absence of role models in rural areas contributes to a lack of aspiration for piped water systems. Without visible examples of successful implementation and the tangible benefits of such systems, rural residents may struggle to envision the value and impact of piped water on their lives.

Personal experience with piped water systems shapes individuals' attitudes and behaviours towards these systems. Role models who have experienced positive transformations in health, sanitation, and overall quality of life due to piped water systems could inspire others and foster a desire for similar improvements within the community lack role models to inspire them to desire piped water. Positive experiences, such as convenient access to clean water and improved living conditions, reinforce the perceived benefits of piped water and increase willingness to pay for continued access.

Table 62: Piped Water Systems Influence Direct Quotation

Participant	*Benefit*	*Illustrative Quote*
Case Study Interview	*Personal*	*"Families who have benefited from piped water systems can attest to*

	experience of benefits	*the positive changes in their daily lives, including improved health, time savings, and economic opportunities. These firsthand experiences build trust and confidence in the reliability and effectiveness of piped water systems."*

The outcomes align with Perceived Usefulness (PU) and Norms (NO). Perceived Usefulness is seen in the direct benefits experienced by those with piped water systems, shaping positive attitudes towards adoption. Norms reflect the influence of role models and their successful experiences, inspiring others to seek similar improvements in their communities.

3.8 Willingness to Pay: Factors Influencing Financial Contribution

Residents' willingness to pay for piped water services was low because of low perceived value, reliability, and convenience. Residents could not see any tangible benefits of reliable water supply hence they could not be motivated to prioritise and invest in sustaining these essential services for their community's well-being.

The observed value of piped water services, including reliability and convenience, influences willingness to pay. Residents are more likely to pay for services they observe as valuable and beneficial to their daily lives.

"If piped water systems consistently provide clean and reliable water supply, residents recognise the value and are willing to pay for the services and to contribute financially to maintain these services." (Case Study Interview).

The findings correspond with Perceived Usefulness (PU) and Economic Cost (EC). Perceived Usefulness is reflected in residents' recognition of the tangible benefits, reliability, and convenience of piped water, which influence their willingness to pay. Economic Cost concerns the perceived value and financial prioritization necessary for sustaining the services.

3.9 Trust in Service Providers and Sustainability of Infrastructure

Trust in service providers and confidence in the sustainability of water infrastructure was lacking thereby affecting residents' willingness to pay for piped water services. Assurances of reliable and affordable water supply from authorities boost trust and encourage financial investment.

Trust in service providers and confidence in the sustainability of water infrastructure affect willingness to pay. Residents are more likely to invest in piped water services if they trust authorities to deliver reliable and affordable water supply over the long-term. The results align with Perceived Behaviour Control (PBC) and Policy Support (PS). Perceived Behaviour Control reflects trust in service providers and the infrastructure's sustainability, influencing residents' willingness to pay. Policy Support includes assurances and effective communication from authorities, which boost trust and encourage financial investment in the services.

Table 63: Trust in Service Providers and Sustainability of Infrastructure

Participant	*Benefit*	*Illustrative Quote*
Case Study Interview.	*Trust of service providers.*	*"Community members are willing to pay for piped water services if they trust service providers to maintain infrastructure and ensure sustainability. Effective communication and demonstration of benefits by neighbours, peers, and family members further enhance trust and willingness to pay."*

Appendix H: Detailed Research Findings B (Chapter 7)

Table 64: Social Influence Dynamics Direct Quotations

Participant	***Aspect***	***Representative Illustrative Quote***
Kapiri Interview 3	*Social Influence*	*"I visited my brother and noticed he had a solar lighting system, so I decided to get the system too. It has been very helpful to me. Depending on how the farming season goes, I might upgrade to the system that includes a TV and radio God willing."*
Mkushi Interview 4	*Social Influence*	*"I observed that the houses of my neighbours had good lighting systems and out of interest, I inquired. I discovered you could get a system through a loan and pay slowly over two years through the mobile telecommunication companies. I did not hesitate and quickly organised some funds, and now I do not have to sleep in the dark and be afraid of being bitten by poisonous snakes."*
Chongwe Interview 4	*Social Influence*	*"I have a solar system that helps me with irrigation. I got the idea from my friend who could grow crops during the dry season. I was shocked and excited at the discovery. I found out the price and the source, organised resources through selling some of my produce, and my children in the city also helped. Now I can enjoy winter maize and water my garden. It also helps me raise income."*
Kapiri Discussion (FGD) 2	*Social Influence*	*"We have come to learn about various systems of solar energy that can be used for irrigation, lighting, and phone charging through intermingling with each other, and now, in this village, everyone has at least one solar-powered gadget or another. The knowledge of solar energy devices has been spreading like wildfire around the whole village."*
Mkushi Discussion (FGD) 2	*Social Influence*	*"Children put us under pressure to improve our quality of life because as they are playing and visiting different relatives and friends, they observe different things and bring back reports. As parents, we are forced to investigate and find out more, and in the process, adopt solar energy systems. It does not feel good when your children keep going to your neighbour because of solar lighting or a solar phone charger. In the end, we work hard to organise funds to pay for the lighting system and buy solar chargers to stop taking phones for charging to neighbours, etc."*
Chongwe Discussion (FGD) 2	*Social Influence*	*"A good number of farmers now have solar irrigation systems and lighting. It started with one person, and before long, others bought the systems after observing and realizing that it is possible. You grow things in the dry and cold seasons and make ends meet. When you observe your friend in the same village, in similar economic circumstances, and can afford to get a solar system, you work hard, realizing that it is possible.*

		Sometimes we used to fear to install solar systems because we were not familiar, and no one owned such systems, but times are now changing."
Commercial Farmer Interview 13	*Social Influence*	*"No one, no NGO, is out there distributing solar panels, and everyone has solar panels. Why? Because they see the value, and they go to the shops, and they get one and bring it home. So, all of our shops sell solar panels everywhere. And like I said, at least - I'm just guessing here - but at least one out of three houses has some form of solar. No one is running a deliberate programme to increase solar uptake; no one is doing anything, but it's a service that people want. So, they go ahead and buy it themselves."*
Commercial Farmer Interview 4	*Social Influence*	*"It may take time for households to see the benefits of new solar technology, but once they do, they are willing to pay for systems that improve their lives. Exposure is crucial, as access to services can stimulate rural communities to generate more revenue, fostering productivity and entrepreneurship."*

Table 65: Community Engagement Deficit Direct Quotations

Participant	***Challenge***	**Representative Illustrative Quote**
Chongwe Interview 4	*Lack of Community Involvement*	*"They brought some free stoves that they claimed used less firewood. Although we all got the stoves, we do not use them because they cannot cook our food like charcoal or firewood due to insufficient heat. The only reason we accepted the so-called improved braziers was because they were free. No one consulted us when creating the braziers. NGOs (aid agencies) are in the habit of wasting money…or maybe someone from the higher offices benefited economically from them, you never know."*
Chongwe Interview 3	*Lack of Community Involvement*	*"Ha ha…do urban people and donors understand us? The kind of lives we live in the village is very different from urban areas and 'kubasungu' (the white man's land). I wish people can take even 6 months and come and live with us and experience what we experience instead of just making decisions in the comfort of their offices."*
Mkushi Interview 2	*Lack of Community Involvement*	*"Just like in a marriage, discussion between husband and wife, even though the husband is the head, is important for things to work and last. In the same way, it's important that people ask us what we really want instead of always dictating the projects that we need. Sometimes they are the right projects but are implemented wrongly due to a lack of consultation."*
Chongwe Interview 6	*Lack of Community Involvement*	*"Politicians come here every election to campaign, but they never talk about solar adoption strategies or encourage us in such areas…all they talk about is farming inputs, roads, schools, clinics etc. Once they win, they disappear till the next election…it's so sad. You are the first person*

		to visit us as a family to talk about solar energy adoption."
Kapiri Discussion (FGD) 1	*Lack of Community Involvement*	*"We can all testify here that you are the first person who has come to interview and talk to us about solar. We just learn about solar energy from our neighbours and when we visit the city or some white farmers' houses."*
Mkushi Discussion (FGD) 2	*Lack of Community Involvement*	*"We might be uneducated, but there is something we can offer, especially pertaining to projects that are implemented in our villages. We know better because we have lived here all our lives, but we are not involved at all, which causes many projects to fail."*
Chongwe Discussion (FGD) 2	*Lack of Community Involvement*	*"We are very excited that you have come to talk to us because we are not consulted about anything. We just see people coming in suits with white people to implement projects."*
Commercial Farmer Interview 7	*Lack of Community Involvement*	*"I worked in Sudan during the Darfur crisis. Communities in the Nuba Mountains, devastated by an 18-year civil war, were starting from scratch. The World Food Programme distributed nearly a billion dollars annually in food aid, while the Food and Agriculture Organization, which focused on sustainable development, was underfunded. This imbalance highlights how free aid often leads to waste and missed opportunities for growth."*

Table 66: Ownership and Sustainability Direct Quotations

Participant	***Challenge***	***Representative Illustrative Quote***
Kapiri Interview 2	*No sense of ownership.*	*"No one consults us. They just implement projects that are already designed elsewhere. Hence, most people, to be honest, do not feel a true sense of ownership at the individual or community level. That's why there is a lack of care, stealing, and vandalism."*
Mkushi Interview 2	*No sense of ownership.*	*"Who is supposed to watch over the free projects that are implemented in our villages? Is it the headman or the community? It's like it's no one's business, and if there is no one to watch over something, it dies naturally. It's like a motherless baby... it can't survive... Laughs."*
Chongwe Interview 3	*No sense of ownership.*	*"Many boreholes have been vandalised and pipes stolen without any serious follow-ups to catch the perpetrators because I think no one cares that much."*
Chongwe Interview 1	*No sense of ownership.*	*"I was young and now I am old, but I have never seen a free project which the town people and whites have brought which has survived the test of time. Rural people are too primitive and wasteful...ha ha. The other problem is that they do not ask us what is best for us but just make decisions in their meetings. Anyway, since they bring free things, we just*

		accept."
Kapiri Discussion (FGD) 2	*No sense of ownership.*	*"We feel like the primary school in the village is part of our own property because, when it was being constructed, each household had to contribute building blocks and other materials that we could manage. It's not much but I feel proud to have contributed and now my children can go to school without walking many miles. The headman and elders coordinated the contributions."*
Mkushi Discussion (FGD) 2	*No sense of ownership.*	*"The solar hammermill that the government installed broke down, and up to now, the problem has not been sorted out."*
Chongwe Discussion (FGD) 2	*No sense of ownership.*	*"We are so grateful for the many projects that aid agencies, and the government bring… free things are nice, but they don't last. There are many projects that have been implemented freely, which sadly have folded quickly."*
Commercial Farmer Interviews 7	*No sense of ownership*	*"In terms of contributions to water projects, rural households provide a small upfront payment to show interest and willingness to participate, though it falls far short of the actual cost. Communities often contribute by laying pipelines, depending on the system type. For borehole systems with hand pumps, communities contribute through insurance policies, making small monthly payments to ensure repairs when needed."*

Table 67: Solar Quality Challenges (Counterfeits) Direct Quotations

Participant	***Challenge***	***Representative Illustrative Quote***
Kapiri Interview 7	*Counterfeits*	*"A person came around the village and sold me a solar panel that looked nice and big, but it only lasted one month and stopped working, and I could not trace him."*
Mkushi Interview 5	*Counterfeits*	*"There are a lot of Chinese solar products sold in Mkushi. It's difficult to know what is real and what is counterfeit. I have spent lots of money on counterfeits because they don't last long even though they are affordable…and there is no way to repair them or return them to the shops. Shops won't agree to take returns, and sometimes we buy from non-stationary vendors."*
Chongwe Interview 2	*Counterfeits*	*"The solar panels I have are very big but not very powerful. When my brother from the city visited, he told me that most of the panel was just decoration and only a small part was used for solar production."*
Kapiri Discussion (FGD 2)	*Counterfeits*	*"Most of us keep buying new solar gadgets every now and then because most of them are Chinese. We have disposed of a lot of them…ha ha…but what can we do? The counterfeits are affordable."*

Mkushi Discussion (FGD 1)	*Counterfeits*	*"Most of us, because of a poor farming season, just buy the cheapest and most affordable gadgets we can find on the market, and sadly, cheap is expensive. But honestly, we have no option. And when these gadgets break, there is no way to repair them, so it's a loss."*
Chongwe Discussion (FGD 2)	*Counterfeits*	*"We are a dumping ground for fake solar products because we are not educated and cannot tell the difference between what's real and fake. But the solar lighting systems supplied through the mobile companies' loan system are of good quality."*
Commercial Farmer Interview 7	*Counterfeits*	*"I live in a town of about 30,000 people, and there are around 1,520 shops selling solar products. However, quality is an issue. The products we get in markets, for example, often don't match their advertised specifications. Many of the solar panels don't produce exactly what is claimed, and it's often less. Quality issues, especially with smaller panels coming from China, are significant. They're not always as good as what is advertised on the back of the panel. However, if you buy from a reputable dealer, the quality is very good."*
Commercial Farmer Interview 11	*Counterfeits*	*"I am one of the few (3%) among the commercial farmers in Mkushi who has fully integrated solar energy into my production, but it's very expensive. I only did it because I promised my mother, who is also very passionate about sustainability. Counterfeits are available and cheap, but commercial farmers are particular about quality, so they avoid counterfeits and buy from reputable, credible, genuine suppliers. The other farmers use ZESCO power, which is much cheaper. The rural farmers, including my workers, fall victim to counterfeits coming from a country I will not mention (China) which has flooded Zambia with many 'fake' solar gadgets…. but at least the counterfeits get the rural people going. It's better than nothing...ha ha."*

Table 68: Entrenched Poverty and Tradition Direct Quotations

Participant	*Challenge*	*Representative Illustrative Quote*
Kapiri Interview 1	*Community Negative Mindset*	*"We were born in poverty, grew up in poverty and we will probably die in poverty together with our children because no one cares about us including our own leaders."*
Mkushi Interview 1	*Community Negative Mindset*	*"We have come to accept our fate that we are nothing because we are not educated, and town people despise us."*
Chongwe Interview 2	*Community Negative Mindset*	*"I don't need assistance from anyone as I have managed to live and survive using the knowledge that I have acquired from within the community. I do not need to be modern or to learn anything extra."*

Kapiri Discussion (FGD) 2	*Community Negative Mindset*	*"We have traditional systems that have worked for us in the areas of medicine, marriage, agriculture, sustainability for hundreds of years which we will hold on. Someone cant just come from outside and tell us what to do. That is disrespectful and offensive. That's why even projects from aid agencies fail."*
Chongwe Discussion (FGD) 2	*Community Negative Mindset*	*"Education is important but its not the most important thing in our village. Starting a family is very important. For example, this Martha (not real name) that is seated over there, was very smart at school but she stopped and got married and now has a husband and three healthy children and a happy family. Maybe now she can go back to school...laughs."*
Commercial Farmer Interview 7	*Community Negative Mindset*	*"When we initially started with the water systems, specifically the piped water systems, we used a post-paid system. At the end of the month, someone would go around, check how much water each household used, and then issue a bill. It was an absolute disaster. We were always seen as the bad guys, constantly chasing people to pay. It was exhausting and ineffective. Eventually, we switched to a prepaid system, and the change was like night and day. Now, people approach us willingly, asking, 'Can I pay for more water?' Instead of us giving them a bill, they take the initiative. It completely transformed the dynamic."*
Commercial Farmer Interview 13	*Community Negative Mindset*	*"Sometimes it's all mind games. By capitalizing on the government's delays in buying or paying for farm produce, middlemen and briefcase buyers often offer extremely low prices to desperate rural farmers, thereby taking the lion's share of the profits from their produce. As commercial farmers, we are assisting some of these farmers in eliminating middlemen and adding value to their produce. However, this effort is not yet widespread, and we are unsure if we will face backlash from the middlemen once they realise their income source is being disrupted."*
Commercial Farmer Interview 14	*Community Negative Mindset*	*"When a practice is repeated over generations, it becomes difficult to break out of that cycle, especially when poverty shapes thought and performance. Many rural people develop self-defence mechanisms to cope with poverty, but these can also prevent them from seizing opportunities for advancement. Encouraging people to recognise and act on opportunities is essential."*

Table 69: Aid Effectiveness and the Importance of Sustainability Direct Quotations

Participant	*Challenge*	*Representative Illustrative Quote*
Commercial Farmer Interviews 2	*NGO Mindset*	*"One of the biggest failures of the NGO community is their reluctance to address the mindset issue. They avoid it, partly because they fear appearing politically incorrect. This hesitance undermines aid*

		programmes, as they do not tackle the deeper roots of poverty, many of which stem from mental and attitudinal barriers."
Commercial Farmer Interviews 7	*NGO Mindset*	*"We frequently clash with large donor agencies like UNICEF, World Vision, and USAID over making communities pay for services. Questions like who will fix a broken pipe or replace a solar panel remain unresolved when systems are provided for free. This lack of sustainable planning is a major issue."*
Commercial Farmer Interviews 16	*NGO Mindset*	*"NGOs often install free systems but do not stick around once their funding ends. This leads to high failure rates, as evidenced by communities where over 70% of boreholes are nonfunctional. Sustainable solutions require a consistent revenue source, meaning communities must pay for services like solar electricity to ensure lasting success."*
Commercial Farmer Interviews 13	*NGO Mindset*	*"It is insulting to view communities as 'too poor' to pay for services. Offering free items perpetuates dependency and reinforces negative self-perceptions. When people see value in a service, they find ways to pay, often raising funds themselves."*
Commercial Farmer Interviews 8	*NGO Mindset*	*"Many aid agencies and donors take an easier path, distributing free items rather than setting up self-sustaining systems. This approach demonstrates either a lack of true compassion or ignorance of rural realities. NGOs often focus more on meeting targets than on genuine human needs."*
Commercial Farmer Interviews 10	*NGO Mindset*	*"Donors, often uneducated about poverty's complexity, want to meet immediate needs without a deeper understanding. Proposing sustainable, business-like models for services can be challenging, as many donors view charging for services as exploitation. Emotional appeals involving free aid are easier to fund."*
Commercial Farmer Interviews 12	*NGO Mindset*	*"Donors may act out of self-interest, giving to feel better about themselves rather than fostering recipients' independence. Teaching skills and investing in sustainable solutions promotes dignity and self-reliance more effectively than simply giving free aid."*

Table 70: Project Misalignment and Dead Aid Direct Quotations

Participant	*Challenge*	*Representative Illustrative Quote*
Kapiri Interview 4	*Misaligned Aid.*	*"You are the first one to come and talk to us about solar PV. No one has ever come to this village to discuss solar PV. Even politicians just come to campaign and all they talk about is boreholes and farming input support, as if that's all we need in life."*

Mkushi Interview 3	*Misaligned Aid.*	*"There are some farmers who have received equipment like tractors, motorcycles, hammer mills, and cooking oil-making equipment, but they don't even put this to good use because they don't know how to maintain and use the equipment properly due to inadequate training, faulty selection of recipients, and sometimes ignorance. The equipment just ends up being wasted."*
Chongwe Interview 4	*Misaligned Aid.*	*"They brought some free stoves that they claimed used less firewood. Although we all got the stoves, we do not use them because they cannot cook our food like charcoal or firewood due to insufficient heat. The only reason we accepted the so-called improved braziers was because they were free. No one consulted us when creating the braziers. NGOs (aid agencies) are in the habit of wasting money… or maybe someone from the higher offices benefited economically from them, you never know."*
Kapiri Discussion (FGD 1)	*Misaligned Aid.*	*"Some of the projects that have been implemented here are good, but again there are many projects which are clearly misaligned and have just been a waste of time and money. For example, health programmes for distributing mosquito nets ended up with nets being used for fishing because of a lack of adequate training. Loans were given to many women without adequate financial literacy training, resulting in misuse of funds and difficulty in repayment."*
Mkushi Discussion (FGD) 1	*Misaligned Aid.*	*"We received free energy-saving braziers that were distributed in various villages but ended up being unused due to insufficient heat for cooking local staple foods like maize meal (nshima), which requires high temperatures. Schools were built without accompanying teacher housing or water and sanitation facilities, causing high teacher turnover and limited utilization of the infrastructure. Yes, the buildings are there, but there are no teachers. There are clinics but no doctors. There are bee-keeping training programmes that were introduced as a source of livelihood, but people sometimes struggle to sell the honey due to difficulties in accessing markets."*
Chongwe Discussion (FGD) 1	*Misaligned Aid.*	*"There are several boreholes that were installed without community consultation, resulting in placement in inconvenient locations. There was a project involving the distribution of goats and cattle, but the recipients were inexperienced and without veterinary support or training, resulting in high animal mortality rates due to diseases, etc. There are no doctors in hospitals and no teachers in schools."*

Appendix I: RUDSHAM Primary Interview Protocol

Informal Disposal, Counterfeit Technologies, and Literacy Challenges in Solar E-Waste Management in Rural Zambia

The interview protocol is designed under the Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM). It aims to investigate user experiences, disposal behaviours, and perceptions surrounding counterfeit solar technologies and e-waste practices in rural Zambia. The tool captures socio-technical, behavioural, and governance-related factors critical for applied energy policy, technology justice, and sustainable waste management in low-income contexts, directly supporting SDG 7.

Section 1: Energy Use, Access, and Technology Experience (PE, PU, PP)

1. How common is solar product use (lights, panels, batteries) in your area?
2. Where do most people buy their solar products?
3. Are these sellers trusted? Why or why not?
4. Have you encountered solar products that failed quickly? What do people think causes this?
5. How do you or others identify genuine versus counterfeit solar products?

Section 2: Disposal Practices, Awareness, and Risks (PBC, GC, CoP, PP)

6. What do you do when a solar product stops working? (probe: keep, sell, burn, bury, dump)
7. Are there local places for dumping or recycling old solar products?
8. Do people here burn, bury, or throw away broken products? How common is this?
9. Are people aware of any health or environmental risks from such disposal?

Section 3: Community Beliefs, Literacy, and Behaviour (NO, PE, GC, CoP)

10. Do most people know solar products may have harmful parts?
11. Do people believe burning or dumping solar products is harmful? Why?
12. Have you or your community received training or advice on solar waste disposal? From whom?
13. Are most people able to read and understand product instructions?
14. How many people in your community can read or understand such instructions?

Section 4: Policy, Governance, and Sustainable Solutions (PS, FMR, CoP, PBC, EC)

15. Do you think there should be rules or recycling places for solar products?
16. What would help people dispose of solar waste safely? (Collection points, awareness, penalties)
17. What role should government, sellers, and community leaders play in managing solar waste and counterfeits?
18. What financing models (like pay-as-you-go, micro-credit) would help people buy safer or authentic solar products?
19. What changes would make solar technologies safer, more durable, and better managed in your community?

20. Do you feel solar PV systems improve your household or community's well-being, income, or energy security? Why or why not?

Appendix J: Ethics Approval

Application for Approval of Research Ethics

Researcher / Student: complete and email to your Supervisor/PI
Supervisor / PI: check and email to:
sbe-undergrad@reading.ac.uk [for BSc research]
sbe-postgrad@reading.ac.uk [for MSc and MArch research]
sbeexecsupport@reading.ac.uk [for PhD, EngD and Staff research]

University of Reading

School of the Built Environment

Section 1 – Project Summary

Project Title: Renewable Energy Adoption, Management, and Innovative financing Mechanisms in Rural Communities. The case of Zambia.

Applicant (Researcher/Student):

Name: Hillary Chanda

Email address: h.chanda@pgr.reading.ac.uk

Status: PhD

Supervisor / Principal Investigator:

Name: Eugene Mohareb

Email address: e.mohareb@reading.ac.uk

Summarize your Research Topic in one or two sentences:

I am investigating the adoption, management and innovative financing mechanisms of solar PV energy in rural communities to gain insights into the best interventions for successful adoption,management and financing of solar PV projects in developing countries.

Is this a Nil Return? NO

If **YES:** Submit your form.

If **NO**: Continue to **Section 2**...

TO SUBMIT YOUR FORM :

- **Applicant:** Read **Section 4** and email it to your Supervisor / PI.
- **Supervisor / PI:** Read **Section 4** and check any relevant Appendices have been completed. Email to relevant address (see top of this page).
- If a Nil Return or Questionnaire/Survey, approval is given by Supervisor/PI submitting the form. Otherwise, the form will be forwarded to REC for approval.

Further Information

Many of the boxes on this form, including this one are deliberately **SPACE LIMITED.**

This **MUST** be your University email address. Using your University email is sufficient to confirm your identity and means we do not require a signature.

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This should be a very short summary of one or two sentences in everyday language, describing **WHAT** you are investigating (e.g. I am investigating green supply chains and how they impact on cost of construction).

Research projects with no ethical issues are classified as 'Nil Return'. Usually this means research using publicly available secondary data.

Projects including the following examples are **NOT** 'Nil Returns' and you should answer 'NO': direct contact with people, personal data, potentially sensitive documents or records, interviews, questionnaires, surveys, safety issues etc.

If you are unsure then reply 'NO'.

A Nil Return is approved by the Supervisor / PI and is not usually checked by the Research Ethics Committee.

Section 2 – Research Methods

BRIEFLY, Describe your Research Methods:

Three Focus Group Discussions (FGD) comprising 10 participants each will be conducted in Mkushi (rural and commercial white farmers FGDs) and Lusaka (rural farmers FGD). Semi structured interviews will comprise 15 households in Mkushi,15 households in Lusaka and 30 key stakeholders consisting 15 renewable energy/ solar PV suppliers and15 government policy makers.A pilot study will be conducted to test the viability of the interview protocol and FGD guide. Simple random sampling will be used.

Please tick all that apply:

- [ ] Questionnaire *(Complete Appendix A)*
- [ ] Simple Survey
- [ ] Environmental Survey

If only these methods are used, then the application is approved by the Supervisor / PI when the form is submitted (as per Page 1). **You do not need to complete Section 3.**

- [x] Interviews *(Appendices B/C and sample questions in Appendix D)*
- [ ] Photos/Filming *(Apps.B/C and add filming notice in App.D)*
- [ ] Other *(Use Appendix D for any other information)*

Applications using these methods will be forwarded on to the Research Ethics Committee for review. **You must complete Section 3.**

Check that you have included any further information as required, using relevant Appendices such as:

- Draft Questionnaire (Appendix A)
- Information sheet for participants (Example in Appendix B)
- Consent form to be signed by participants (Example in Appendix C)
- Draft Interview Questions (Use Appendix D)
- Public Notices e.g. filming (Use Appendix D)
- Recruitment Adverts (Use Appendix D)

Further Information

This should be a summary of **HOW** you will investigate your topic. Describe, in no more than a few sentences, the methods you will use (e.g. interviews, filming, observation, analysis of documents, photography, focus groups, etc.) Include details such as: what type of data, you will gather, how many participants, how they will be approached, what they will do, if/how you will be accessing documents, etc. If you are interviewing, use Appendix D to provide examples of questions. If you are filming or photographing, describe how you will anonymize images. If filming in a public place, use Appendix D to attach your public filming/photography notice.

Where reasonably possible, you should provide every participant in your research with an Information Sheet (Appendix B), and obtain from them a signed Consent Form (Appendix C). If for ANY REASON you are unable to do this, you should contact your Supervisor / PI or the Research Ethics Committee.

Three research methods are approved by the Supervisor/PI and not usually checked by the Research Ethics Committee:

Questionnaire (set of questions asked face-to-face or remotely)

Simple Survey (e.g. observing or documenting things other than people)

Environmental Survey (data from sensors, with permissions as appropriate)

Questionnaires MUST include a consent statement (which might be given verbally) to clarify issues such as: confidentiality, voluntary participation, anonymity, data management, informed consent, etc. (see example in Appendix A). Environmental Surveys should include a brief description including: type of sensors, location of sensors, permissions required etc.

Supervisors should assess these on a case-by-case basis. If in any doubt, also tick the 'Other' box to refer the application to the REC for approval, and complete Section 3 to describe and consider any ethical issues.

Section 3 – Ethical Issues

Outline your ethical issues, and how you intend to deal with them:

Ethical issues like confidentiality,privacy,respect and anonymity will be observed.Permission will be solicited before interviewing and recording interviews. Questions will be interprated in local language understood by partipants.Participants will be given the right to make changes within a specified period after the interviews. Instead of giving personal details, participants will be allocated unique codes by which they will be identified.The list will be held in a separate file and kept in a locable cabinet.All documents will be stored under password-protection on my computer and backed up to the University server via one drive. Files will be stored in a locable cabinet.Participants will not be paid any money to participate.Data will be stored/deleted as per University guidlines. Four research assistants with a atleast a Bachelors degree will be trained to adhere to ethical standards.

If your research involves any of the following, your application may be raised with the University Research Ethics Committee.

- Medical procedures or samples?
- Patients or clients of the NHS?
- Psychological research using human participants?
- People unable to give informed consent?
- Educational research?
- Food research?
- The use of sensitive or personal data?
- Participants who are in a 'Special Relationship' with you
- Deception

Does your research involve any of the above? No

How will you store your data (including signed Consent Forms)?

All data and signed consent forms will be stored on a password protected computer and securely kept in a locable cabinet. Data and consent forms will be returned to SBE once I complete and leave SBE.

How long will you retain your data?

The data will be retained for 3 years post research by default as per University of Reading guidlines.

Further Information

Issues might include: confidentiality, privacy, anonymity, compromising participants by asking them to reveal sensitive information, controversial research topics, proprietary technical information, involvement of young or vulnerable people, existing relationships with participants (student, spouse etc.), cultural or language differences, coercion or deception, place of interaction (public place, workplace, hazardous environment etc.), revelation of criminality, uncovering health issues, exposure to pain or distress, physical contact generally, consumption of food or drink, risk to personal safety of the researcher and the participants, inconvenience or intrusion, environmental impact.

THIS LIST IS BY NO MEANS EXHAUSTIVE - YOU MUST IDENTIFY ALL ISSUES RELEVANT TO YOUR OWN PROJECT AND EXPLAIN HOW YOU WILL DEAL WITH THEM.

If an application to the University Research Ethics Committee is required, you will be contacted by the SBE Ethics Committee. If you are unsure, please contact the SBE Ethics Committee before submitting your application. People 'unable to give informed consent' are usually children or vulnerable adults. It is a legal requirement that staff and students undergo a Disclosure and Barring Service check before engaging in research when in a position of trust. 'Special Relationship' includes for example: spouse/partner; employer/employee; teacher/student etc.

All data, including signed consent forms, must be stored securely (e.g. on a password protected laptop; in a locked office, etc.) All data and consent forms must be removed from personal storage and returned to SBE (usually to the supervisor/PI) if/when the researcher leaves SBE.

BSc / MSc dissertation data would usually be destroyed 1 year after completion. PhD / Staff research data should be retained for 3 years post-research by default. Research supported by external funders may have specific requirements (e.g. note RCUK requirements).

Section 4 – Confirmation

Applicant:

- To the best of my knowledge I have made known all relevant information to the Research Ethics Committee, and I undertake to conduct this research in line with the information provided. I will inform the committee of any such information that subsequently becomes available, whether before or after the research has begun.
- **To confirm this statement, please email the completed form (including the APPENDICES as required) to your Supervisor / PI (from your University email address)**
- NO FURTHER ACTION IS REQUIRED

Supervisor / PI:

- I have checked the content of this form and the attachments, and to the best of my knowledge I have made known all relevant information to the Research Ethics Committee, and I undertake to inform the committee of any such information that subsequently becomes available, whether before or after the research has begun.
- **To confirm this statement, please email the form (from your University email address) to:**
  sbe-undergrad@reading.ac.uk [BSc]
  sbe-postgrad@reading.ac.uk [MSc and MArch]
  sbeexecsupport@reading.ac.uk [PhD, EngD and Staff]
- NO FURTHER ACTION IS REQUIRED

Further Information

It is important that if you have any queries, you discuss with your Supervisor / PI or contact the SBE Ethics Committee before submitting this form.

Using your University email is sufficient to confirm your identity and means we do not require a signature.

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Appendix A - Draft Questionnaire / Survey

Use this page if you are conducting a questionnaire or survey. Surveys often do not allow for the distribution of information sheets and signed consent forms. To obtain informed consent, researchers should begin the survey with a short paragraph informing participants of the nature and topic of the project and indicating that by completing the survey, they are consenting to participate.

Copy / Paste your Draft text into the box below. You might simply edit the example text already given. Note, THIS IS ONLY AN EXAMPLE, any relevant information must be modified to suit your project, including all that **RED** text in *italics* (right click on text to select/remove italics). Include a representative selection of your draft questions. Do not exceed this one page.

Appendix B - Draft Information Sheet

Use this page if you are conducting interviews or face-to-face meetings (e.g. observations, focus groups etc.) Each participant should be informed of the purpose and methods of the research, on an Information Sheet. This should be on University of Reading headed paper, and MUST include contact details for the researcher and supervisor / PI. Leave a signed copy of the Information Sheet with the participant.

Copy / Paste your draft text into the box below. You might simply edit the example text already given. Note, THIS IS ONLY AN EXAMPLE, any relevant information must be modified to suit your project, including all that **RED** text in *italics* (right click on text to select/remove italics). Include a representative selection of your draft questions. Do not exceed this one page.

University of Reading

Hillary Chanda
School of the Built Environment
University of Reading
Whiteknights
Reading
RG6 6AW

Information sheet to be left with the participant.

Renewable Energy Adoption, Management, and Innovative financing Mechanisms in Rural Communities. The case of Zambia.

My name is Hillary Chanda and I am a PhD student in Construction Management, from the School of the Built Environment at the University of Reading. I am carrying out research on Solar PV renewable energy adoption, management and innovative financing mechanisms in rural areas of developing countries. The main aim is to gain insights into the best interventions for successful adoption,implementation, maintenance and financing of solar PV projects in developing countries.
If you are willing to be interviewed you will be asked to participate in an interview of about 60 minutes, at a time and place of your choice. During the interview I will ask you questions on your experience with current energy practices. I will also ask you about your views on solar PV energy adoption, management and financing mechanisms. With your permission, I would like to tape the interview and transcribe section later. Copies of the transcript will be available on request and any changes which you ask for will be made.

You can choose not to answer any questions. You are free to withdraw from the study at any time.
At every stage, your identity will remain confidential. Your name and all identifying information will be removed from the written transcript. My supervisor and I will be the only people who will have access to this data. The data will be kept securely and destroyed when the study has ended, which will be a maximum of 12 months from the completion of the research. The data will be used for academic purposes only. Copies of any outputs, such as articles or presentation slides, will be available on request.

If you have any questions or concerns, please contact me at h.chanda@pgr.reading.ac.uk, or my supervisor at my.supervisor at e.mohareb@reading.ac.uk
This project has been subject to ethical review, according to the procedures specified by the University Research Ethics Committee, and has been given a favourable ethical opinion for conduct.

Researcher's Signature:

Date:

Appendix C – Draft Consent Form

If the participant is happy to be part of your research project, they need to confirm this by signing a Consent Form. If interviews are conducted remotely (e.g. Skype) the research and details of consent should be described, and consent given verbally. This should be explicitly recorded in the interview notes. CONSENT FORMS MUST BE RETAINED IN ACCORDANCE WITH YOUR DATA MANAGEMENT PLAN (Section 3) AND RETURNED TO SUPERVISOR/PI PRIOR TO LEAVING SBE.

Copy / Paste your Draft text into the box below. You might simply edit the example text already given. Note, THIS IS ONLY AN EXAMPLE, any relevant information must be modified to suit your project, including all that **RED** text in *italics* (right click on text to select/remove italics). Include a representative selection of your draft questions. Do not exceed this one page.

University of Reading

Hillary Chanda
School of the Built Environment
University of Reading
Whiteknights
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Renewable Energy Adoption, Management, and Innovative financing Mechanisms in Rural Communities. The case of Zambia.

Participant Consent Form - to be retained by the researcher

1. I have read and had explained to me by Hillary Chanda the Information Sheet relating to this project and any questions have been answered to my satisfaction.
2. I understand that my participation is entirely voluntary and that I have the right to withdraw from the project any time, and that this will be without detriment.
3. I understand that my personal information will remain confidential to the researcher and his/her supervisor at the University of Reading, unless my explicit consent is given.
4. I understand that my organisation will not be identified either directly or indirectly without my consent.
5. I agree to the arrangements described in the Information Sheet in so far as they relate to my participation.

Participants Signature:
Date:

Appendix D – Any Other Information

(e.g. Draft Interview Questions; Recruitment adverts etc.)

Use this Attachment page to include any other information, including: representative interview questions,leaflets, adverts, recruitment emails etc. If you are filming or photographing include the public notice that you need to place where it can be seen at the start and end of the area in which you are capturing images.

This needs to provide enough detail for the Ethics Committee to understand what you are doing and the ethical issues involved.

Copy/paste images or text, or type in, but do not exceed this one page.

Sample Questions of Suggested Interview Protocol for Focus Group Discussions
Facilitator's welcome, introduction and instructions to participants
Welcome and thank you for volunteering to take part in this focus group. My name is Hillary Chanda, I am a PhD student at University of Reading. I have come with four assistants. I realize you are busy, and I greatly appreciate your time. We are having discussions on energy sources and solar PV with several people in this area and for that reason you were invited.
Introduction: This focus group discussion is designed to get your views and experiences regarding your current and desired energy sources and uses. The focus group will take no more than 60 minutes.
You have probably noticed the recorder. We are tape recording the session because we do not want to miss any of your comments. People often say very helpful things in these discussions, and we cannot write fast enough to get them all down. We will be on a first name basis, and we will not use any names in our reports. You may be assured of complete confidentiality. I will now explain the key points of this information sheet.
Ground rules:

- My role as moderator will be to guide the discussion
- One person speaks at a time.
- Please feel free to share your point of view even if it differs from what others have said. There are no right or wrong answers but rather differing viewpoints. Feel free to bring out both positive and negative comments.
- You can speak in any order.
- Please feel free to express yourselves without fear.
- You do not have to agree with the views of other people in the group.
- We ask that you turn off your phones. If you cannot and if you must respond to a call, please do so as quietly as possible and re-join us as quickly as possible.
- Does anyone have any questions?
- OK, let's begin

Warm up:
We have placed name cards on the table in front of you to help us remember each other's names. Let's find out some more about each other by going around the table.
Introductory question:
Am just going to give you a couple of minutes to think about your experience with energy and knowledge about solar PV. Is anyone happy to share his/her experience?
Guiding questions:

- Kindly enlighten us on the energy sources you use and why?
- Explain how you currently finance the energy sources you use.
- Mention what you like about the current energy source.
- Mention the four most important uses of energy in order of importance.

Appendix D – Any Other Information

(e.g. Draft Interview Questions; Recruitment adverts etc.)

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Copy/paste images or text, or type in, but do not exceed this one page.

• Tell us about some disadvantages and disappointments you have experienced with the current energy source.
• What influenced your decision to use this energy source?
• In choosing your preferred energy source, what are the most important things you look for?
• Think about the times when you have run out of energy. What reasons could have caused this gap?
• Tell about solar PV and what you know about it.
• What are the advantages and disadvantages of solar PV energy source?
• Tell us if you would prefer solar PV over your current energy source.
• What are the barriers to the successful adoption and use of solar PV energy?
• In your opinion, how can the community work together to finance, manage and provide solar PV?
• Tell us about the support that you get to enhance energy from the government or other partners.
• Explain how you have participated in community projects and what benefits you accrued.

Concluding question:

• From today's discussion, what would you say are the most important issues you would like to express about energy use and solar PV energy?

Conclusion:

• Your participation is much appreciated.
• I am glad to inform you that our discussion was a success.
• Your opinions will play a critical role to the research.
• We hope you had a good and interesting discussion time.
• If there is anything you are unhappy with or wish to complain about, please don't hesitate to contact me or the local research assistant
• I would like to remind you that any comments featuring in this report will be anonymous and access to this report will be restricted.

Sample Questions of Suggested Interview Protocol for Rural Farmers

PE – Perceived Ease – Degree of ease in installation, use, maintenance, accessing experts.

• How do you find the process of installing solar PV panels?
• Explain the main uses of solar PV power?
• How are solar PV panels maintained?
• Tell us your experiences about solar PV experts' availability.

PU – Perceived Usefulness – Degree of dependability, tech reliability, energy security, improvement over existing power source, productive use.

• In your opinion, how dependable and reliable are solar PV panels?
• Explain how solar PV energy compares to traditional energy in terms of security.

Appendix D – Any Other Information

(e.g. Draft Interview Questions; Recruitment adverts etc.)

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• In what ways can solar PV energy be used for productive purposes?
NO – Norms – Compatibility, social norms, household norms, social acceptability, people's opinions, people's experiences.
• What compatibility challenges do you face with solar panels regarding your house design?
• In what ways can solar energy systems be integrated in the culture?
• What traditional or other power sources are normally used apart from solar energy?
• In what ways are solar panels accepted as a good energy source?
• Do individuals prefer solar energy over other energy sources?
• What experiences and opinions do people have over solar energy?
PBC – Perceived Behaviour Control – Return warranty, ability to choose configuration, guarantee, freedom, and ability to choose to buy.
• Tell us your experience as regards return warranty and guarantee.
• What has been your experience when it comes to freedom to choose configuration or right to buy or not to buy solar PV.
• Outline any challenges and times when you felt that you had no choice?
PS – Policy Support – Incentives, subsidies, government support, UNSDGs, solar PV suppliers, communication.
• In what ways does the government support the enhancement and provision of solar PV in rural areas?
• Explain the main benefits that you have enjoyed from partnerships with government?
• What challenges are there when it comes to support?
• What are your major expectations as regards government support?
• Give a detailed description of the adequacy of the communication regarding advantages and disadvantages of using solar energy from the government, suppliers, NGO's and community leaders?
EC – Economic Cost – Solar PV price will affect my decision to buy and increase my energy expenditure.
• Tell us what you think about the pricing of solar panels?
• What are the main maintenance costs of solar panels?
• What economic benefits does solar energy present to you?
• Outline the advantages of solar energy over traditional energy sources?
CoP – Community Participation – Degree to which the community owns the projects and degree to which community is consulted and involved in designing, financing, and maintaining the solar PV systems. Supplier engagement.
• Describe any successful community energy projects that you have experienced?
• To what extent do you think you have ownership of the community projects?
• Tell us the best way for communities to partner without the government/other partners.
• Explain how you are involved in designing, financing and maintaining solar PV systems?

Appendix D – Any Other Information

(e.g. Draft Interview Questions; Recruitment adverts etc.)

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This needs to provide enough detail for the Ethics Committee to understand what you are doing and the ethical issues involved.

Copy/paste images or text, or type in, but do not exceed this one page.

• Do you feel community opinions are taken seriously, respected, incorporated and implemented?

PP – Prior Preferences and Practice – Current energy practices and preferences and reasons. Most important uses of energy, why they are preferred, expectations.

• Describe the current energy source you use and why?
• What do you consider as the top 5 most important uses of energy in rural areas currently?
• What is your most preferred energy source and why?
• Would the community be willing to replace their current energy source with solar PV energy? Under what conditions?
• Would you prefer a similar but improved version of the energy source you currently have over solar PV energy? Give reason.
• How and in what ways would you like the current preferred energy source to be enhanced or modernised?
• What are your expectations of a better, modern and affordable energy source?

GC – Green Concern – Concern for environment. Awareness of impact at individual, household, and community level.

• What major concerns do you have over managing the environment?
• In what ways can people help to conserve the environment?
• Explain how the government or NGOs are involved in ensuring that the environment is protected?
• Has the rainfall pattern changed in the last ten (10) years? Give reason?

FMR – Financial Models of Relevance. The degree to which current finance practices if they exist compare with the 5P and other relevant solar PV financial models in other parts of the world and to what extent can they best be replicated and adopted in the developing world context.

• Tell us how you think you can partner with the government in running community energy projects?
• How can the community create capacity to take part in PPP?
• What would be the best way for the rural community to partner with the government or the private sector?
• Can you suggest any innovative ways in which the communities can contribute to solar PV energy projects.